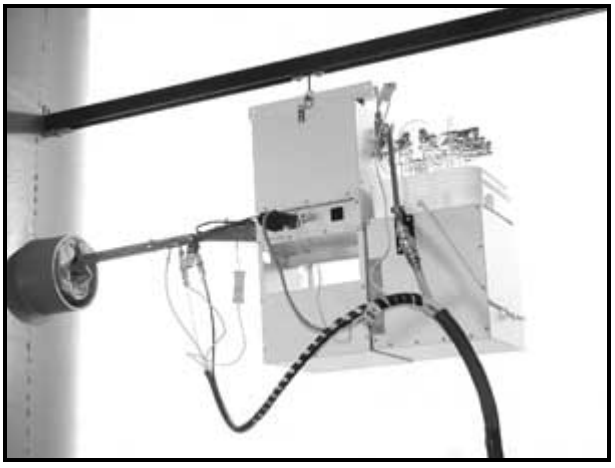
Method

5

APEX INSTRUMENTS, INC.

Isokinetic Source Sampler (500-Series Models)



Operator's Manual

ISOKINETIC SOURCE SAMPLER –MC500 SERIES

Operator's Manual

Apex Instruments, Inc.
204 Technology Park Lane
Fuquay-Varina, NC 27526 USA
Phone 919-557-7300 • Fax 919-557-7110
Web: www.apexinst.com
E-mail: info@apexinst.com

Revision No: 4
Revision Date: February 2003

TABLE OF CONTENT

INTRODUCTION 1

SYSTEM DESCRIPTION 3
Source Sampler Console 4
Electrical Subsystem 6
Thermocouple Subsystem 7
Vacuum Subsystem 7
External Vacuum Pump Unit.....8
Probe Assembly 9
Probe Liner 10
Probe Heater 11
Probe Sheath 11
Small Parts Kit 11
Modular Sample Case 12
Umbilical Cable with Umbilical Adapter.....14
Glassware Sample Train 15

OPERATING PROCEDURES.....17

SET-UP AND CHECK OF SOURCE SAMPLING SYSTEM 17
Initial Set-up Procedure 17
System Check.....19
Initial Sampling System Leak Check 19
TEST DESIGN.....20
SITE PREPARATION.....20
ASSEMBLING SAMPLING EQUIPMENT AND REAGENTS.....25
PRELIMINARY MEASUREMENTS OF GAS VELOCITY, MOLECULAR WEIGHT AND MOISTURE.....25
METHOD 1 – DETERMINING SAMPLE AND VELOCITY TRAVERSE POINTS.....26
METHOD 1A – SAMPLE AND VELOCITY TRAVERSES FOR SMALL STACKS OR DUCTS 32
METHOD 2 – STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE.....33
Static Pressure.....36
Barometric Pressure 36
Stack Gas Molecular Weight and Moisture.....37
METHOD 3 – GAS ANALYSIS FOR DRY MOLECULAR WEIGHT.....38
METHOD 4 – MOISTURE CONTENT OF STACK GAS40
Reference Method 4.....41
Approximation Method.....43
METHOD 5 – DETERMINATION OF PARTICULATE EMISSIONS.....46
METHOD 5 TEST PROCEDURE.....48
RECOMMENDED READING LIST FOR ISOKINETIC SAMPLING 60

CALIBRATION & MAINTENANCE.....61

CALIBRATION PROCEDURES 61
Dry Gas Meter and Orifice Tube.....63
Metering System Leak Check Procedure (Vacuum Side) .63
Metering System Leak Check Procedure (Pressure Side) .64
Initial or Semiannual Calibration of Dry Gas Meter and Orifice Tube 65
Post-Test Calibration of the Source Sampler Console 67
Calibration of Thermocouples.....68
Calibration of Pressure Sensors.....70
Calibration of Pitot Tube 71
Calibration of Sampling Nozzles.....73
Initial Calibration of Probe Heater.....74
MAINTENANCE.....75
External Pump Assembly.....75
Source Sampler Console 79
Dry Gas Meter.....79
Dual Column Inclined Manometer 80
Manometer Zero Solenoid Valve.....80
Temperature Controllers 82
Thermocouple Wiring and Thermocouple Display.....82
Electrical Power Circuits.....83
Circular Connector Outlet on Source Sampler Console....83
Umbilical Cable 83
Modular Sample Case 84
Probe Assembly Tube Heater 84
Sample (Vacuum) and Pitot (Pressure) Lines on Umbilical Cable 84
Quick-Connects.....84
Vacuum Line.....84
Pitot Lines 84

APPENDIX A……..A-1

RECOMMENDED EQUIPMENT FOR ISOKINETIC SAMPLING……A-2
RECOMMENDED SPARE PARTS……..A-3
EQUIPMENT CHECKLIST……A-5

APPENDIX B……...B-1

ELECTRICAL & PLUMBING SCHEMATICS...……...B-2

APPENDIX C……...C-1

CALIBRATION DATA SHEETS……C-2

APPENDIX D……...D-1

STACK TESTING FIELD DATA SHEETS……D-2

APPENDIX E……E-1

CALCULATION WORKSHEETS……E-2

Chapter

1

Introduction

The purpose of this manual is to provide a basic understanding of the Apex Instruments Model MC-500 Series Source Sampler console and isokinetic sampling system. Sections of the manual include System Description, Calibration Procedures, Sampling Procedures and Maintenance and Troubleshooting. The manual is based on the procedures established by the United States Environmental Protection Agency (USEPA) in accordance with Reference Methods 1 through 5 – Determination of Particulate Emissions from Stationary Sources.

The Apex Instruments isokinetic source sampling system enables the operator to extract a gas sample from a stack *isokinetically*. The word "isokinetic" is comprised of two Greek root words "iso" meaning "the same as" and "kinetic" meaning "relating to motion of material bodies." Isokinetic sampling is therefore the extraction of a gas sample from a gas stream at the same velocity as the gas travels in the stack. Isokinetic sampling is necessary because of the inertial effects of particulate matter in a gas stream. The isokinetic sampling ratio, or percent isokinetic (%I), is the ratio of the sample velocity at the inlet of the sampling nozzle to the stack gas velocity.

Isokinetic testing requires a through understanding of the first five test methods presented in Title 40 Part 60 Appendix A of the Code of Federal Regulations (40CFR60 App. A). Method 5 provides the general sampling train operation protocol but Methods 1 through 4 prescribe techniques underpinning the sampling activities associated with Method 5. Together, these methods outline the basic protocols for determining particulate concentrations and mass emission rates.

Method	**Description**
Method 1	Determination of Sampling Location and Traverse Points
Method 2	Determination of Stack Gas Velocity and Volumetric Flowrates
Method 3	Determination of Dry Molecular Weight and Percent Excess Air
Method 4	Determination of Moisture Content
Method 5	Determination of Particulate Matter Emissions from Stationary Sources

The basic Method 5 sampling train is easily adapted to test for many other gaseous and particulate parameters of interest from stationary sources. Parameters of interest may include metals, polychlorinated biphenyls (PCBs), dioxins/furans, polycyclic aromatic hydrocarbons (PAHs), particle size distributions and an ever-increasing group of pollutants by adaptations of basic test methods. While the different methods are designated by other US EPA or agency method numbers, they are variations of Method 5 procedures such as using: different impinger solutions, organic resin traps, different filter media, sampling temperatures or a range of other alternative procedures.

The Model MC-500 Series Sampling System is applicable for the following isokinetic test methods and pollutants:

Method No.	Pollutants
5A	PM from Asphalt Roofing
5B	Non-sulfuric Acid PM
5D	PM from Positive Pressure Fabric Filters
5E	PM from Fiberglass Plants
5F	Non-sulfate PM from Fluid Catalytic Cracking Units
5G	PM from Wood Stoves - Dilution Tunnel
5H	PM from Wood Stoves - Stack
8	Sulfuric Acid Mist, Sulfur Dioxide and PM
12	Inorganic Lead (Pb)
13A & 13B	Total Fluorides
17	Particulate Matter
23	Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans
26A	Hydrogen Halides and Halogens
29	Multiple Metals
101	Mercury (Hg) from Chlor Alkali Plants
101A	Mercury (Hg) from Sewage Sludge Incinerators
104	Beryllium (Be)
108	Inorganic Arsenic (As)
111	Polonium-210
201A	PM_{10} Particulate Matter (Constant Sampling Rate)
202	Condensable Particulate Matter
206	Ammonia (Tentative)
207	Isocyanates (Tentative)
306	Hexavalent Chromium from Electroplating and Anodizing Operations
315	PM and Methylene Chloride Extractable Matter (MCEM) from Primary Aluminum Production
316	Formaldehyde from Mineral Wool and Wool Fiberglass Industries (Proposed)

Waste Combustion Source Methods in EPA-SW-846

Method No.	Pollutants
0010	Semivolatile Organic Compounds
0011	Formaldehyde, Other Aldehydes and Ketones
0023A	Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans
0050	Hydrogen Chlorine and Chlorine
0060	Multiple Metals
0061	Hexavalent Chromium

System Description

The Apex Instruments isokinetic source sampling system consists of five (5) main components, shown in Figure 1-1:

1. Source Sampler Console, includes a dual column manometer, sample flow control valves with orifice flow meter, dry gas meter, and electrical controls.
2. External Vacuum Pump Unit, includes pump, hoses with quick-connect fittings and lubricator.
3. Probe Assembly, includes a removable probe liner, removable tube heater encapsulated in a protective probe sheath with pitot tubes/stack temperature/orsat line quad assembly.
4. Modular Sample Case, includes hot box for filter assembly, cold box for impinger glassware, and electrical connections.
5. Umbilical Cable, includes all electrical and pneumatic lines to connect the Modular Sample Case with the Source Sampler Console.

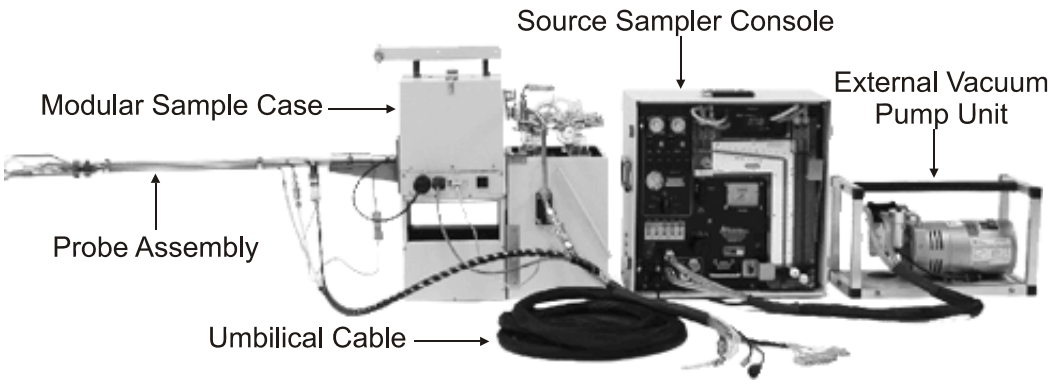


Figure 1-1 Apex Instruments Isokinetic Source Sampling Equipment

Source Sampler Console

The Source Sampler Console is the operator's control station that monitors gas velocity and temperatures at the sampling location, and controls system sampling rate and system temperatures. Figure 1-2 illustrates the Apex Instruments Model MC-572 Source Sampler Console's front panel. The Model 572 is the metric version of the Model 522.

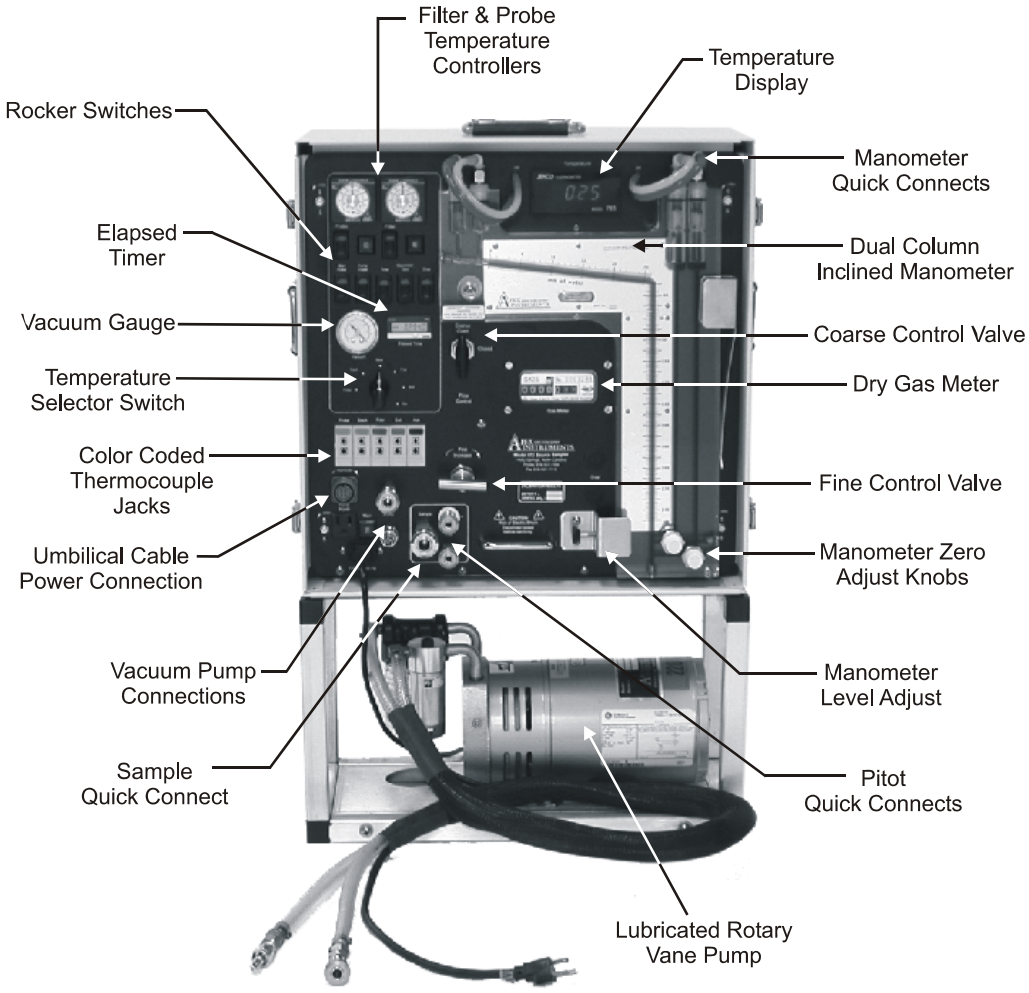


Figure 1 -2 Model MC-572 Source Sampler Console Front Panel

Assembly in the field is simple. The connections for sample line, pitot tube lines, vacuum pump (non-reversible), and electrical (4-pin and thermocouple) are located on the front panel for easy access.

The front panel has four (4) latches -- one in each corner -- that unscrew and enable the operator to pull out the Source Sampler Console from the cabinet using the convenient handle.

Table 1-1 presents a comparison of the features and specifications of each Apex Instruments Source Sampler Console. The Series 500 Source Sampler Console includes:

- Double-Column Inclined/Vertical 250-mm (10-inch) Manometer and Flow Control Valves to monitor stack gas velocity pressure head and orifice pressure to achieve isokinetic sampling.
- Dry Gas Meter that reads gas sample volume in cubic meters (or cubic feet) to three decimal places.
- Automatic, Solid-State Temperature Controllers with individual circuit breakers for filter hot box (oven) and probe heat.
- Digital Temperature Display and 6-channel Thermocouple Selector Switch enable the operator to monitor all sampling system temperatures.
- Vacuum Gauge reads system vacuum 0-100 kPa (0-30 in. Hg).
- Digital Elapsed Timer monitors sampling time by the on/off toggle switch.
- Manometer Zero switch enables the operator to zero the Orifice Tube manometer at any time before or during sampling, using direct-acting solenoid valves.

Table 1-1 Features and Specifications of Apex Instruments Model MC-500 Series Console Meters

Features	**MC 522**	**MC 572**
Gas Meter	Rockwell 110, direct read index, 0.1 cubic feet/revolution, res 0.001 cubic feet	Kimmon SK-25 with direct read numeric index, 68 Lpm rated capacity, 0.1 liter res, with flow indicator for leak checks
Meter Display	Direct reading numeric totalizer with 9999.999 cubic feet capacity	Direct reading numeric totalizer with 9999.999 cubic meter capacity
Temperature Control	Analog solid-state controllers with solid-state power relay external relay, 120 VAC/5A or 240 VAC/3A resistive load	Analog solid-state controllers with solid-state power relay external relay, 120 VAC/5A or 240 VAC/3A resistive load
Temperature Display	3½ digit red LCD display, -15°F to 1999°F range, with external 7-channel selector switch	3½ digit red LCD display, -105°C to 1372°C range (°F available), with external 6-channel selector switch
Sample Pump	Rotary Vane Pump (Standard) Double-Head Diaphragm (Optional) See Descriptions Below	Rotary Vane Pump (Standard) Double-Head Diaphragm (Optional) See Descriptions Below
Umbilical Connections	Electrical: 4 pin circular connector Sample Line: 12.7 mm (1/2 inch) quick connects Pitot Line: 6.35 mm (1/4 inch) QCs (3/8 inch Optional) Thermocouples: Type K standard size	Electrical: 4 pin circular connector Sample Line: 12.7 mm (1/2 inch) quick connects Pitot Line: 6.35 mm (1/4 inch) QCs (3/8 inch Optional) Thermocouples: Type K standard size
Dimensions	19x19x10¾ inches (metric: 49x49x26cm)	19x19x10¾ inches (metric: 49x49x26cm)
Power	120 V / 60 Hz 240 V / 50 Hz Optional	120 V / 60 Hz 240 V / 50 Hz Optional
Weight	40 lb (19.5 kg)	19.5 kg (40 lb)

The Source Sampler Console has Electrical, Thermocouple, and Vacuum sub-systems.

Electrical Subsystem

The Source Sampler Console is factory-configured for 120VAC/60Hz electrical power. Configuration for 240VAC/50Hz operation is an available option. The Electrical Schematics for the Source Sampler Console are presented in Appendix B.

All circuits are protected by three (3) front panel mounted circuit breakers. These circuit breakers detect and interrupt overload and short circuit conditions, providing an important safety factor. If the circuit breaker opens, or "trips," indicating interruption of the circuit, investigate and repair the electrical fault. Then, reset the breaker by pressing the circuit breaker switch.

The circuit breaker can also "nuisance trip" making it difficult to complete a test. To reduce the probability of nuisance tripping, the circuit start-up sequence can reduce the power surge. The optimum start-up sequence is to power up the pump first, as this has the highest current and start-up surge demand. The filter and probe heaters can be powered seconds after the pump has started.

The electrical subsystem provides switched power to several circuits, which are: MAIN POWER, PUMP POWER, MANOMETER ZERO, TIMER, PROBE heater and OVEN heater.

- The MAIN POWER switch controls all power to all circuits within the source sampler. Also, when this switch is on, the cabinet cooling fan should operate.

- To activate the pump unit, plug the pump power cord into the Source Sampler Console receptacle and turn on the PUMP POWER switch.

- The MANOMETER ZERO switch operates two (2) 3-way solenoid valves. These valves open both legs of the ΔH side of the dual-column manometer to atmosphere so that the manometer fluid zero pressure level can be checked and, if necessary, adjusted by the operator. When the MANOMETER ZERO switch is ON, the valves should produce an audible "click."

- The timer will begin to count when the TIMER switch is turned on and stops when the switch is turned off. The display is reset to zero with a push switch on the face of the timer display. The timer is factory-set to read hour/minutes/seconds but can read minutes and tenths of minutes if specified in the purchase order.

- To activate the heaters in the filter compartment (Hot Box) and the probe heater turn on the switches labeled FILTER and PROBE. The indicator lights on the automatic temperature controllers will illuminate. Adjust the dials to approximately 120°C (248°F) and check the temperature display to verify if the heaters are working. Allow time for the temperatures to stabilize and verify operation of the circuits.

Thermocouple Subsystem

The thermocouple subsystem displays, measures and/or controls temperatures critical to isokinetic sampling operation. The thermocouple system consists of Type K thermocouples, extension wires, male/female connectors, receptacles, a 6-channel selector switch and a digital temperature display with internal compensating junction.

There are automatic temperature controllers for probe and filter oven heat which receive an input signal from the electrical subsystem and maintain these temperatures within a close range of the set point. The temperature controllers are solid-state analog devices with a dial control. Digital programmable temperatures controllers are optional. The thermocouple electrical diagram is presented in the Electrical Schematic.

Vacuum Subsystem

The vacuum subsystem consists of an external vacuum pump assembly, quick-connects, internal fittings, two (2) control valves (Coarse and Fine), an orifice meter and a dual-column inclined manometer.

The external vacuum pump assembly provides the vacuum for extracting the gas sample from the stack and then through the various components of the isokinetic source sampling system.

The sample flow rate is controlled by the Coarse Control Valve and the Fine Increase Valve. The Coarse Control Valve is a ball valve with a 90° handle rotation from closed to full open. This valve blocks the flow from the SAMPLE inlet quick-connect to the Vacuum Pump inlet.

The Fine Increase Valve is a needle-type valve with four (4) turns from closed to full open. The Fine Increase Valve allows flow to recirculate from the pump outlet back to the pump inlet. This dual valve configuration enables very precise control of the sample flow rate.

A calibrated Orifice Tube located on the outlet of the Dry Gas Meter to indicate the sample flow rate. The orifice pressure drop is measured on the ΔH (front or orange) side of the dual-column manometer. The stack gas velocity pressure drop is measured on the Δp (back or red) side of the manometer. By observing the orifice reading (ΔH) on the manometer, the operator can quickly adjust the sample flow rate using the Fine Increase Valve so that the sample is extracted under isokinetic conditions.

The Manometer Zero switch on the front panel enables the operator to adjust the ΔH manometer before or during a sampling run. By switching to ON, solenoid valves are actuated to vent the pressure lines to atmosphere and the operator can adjust the manometer's fluid level using the knobs located at the bottom of the manometer. To zero the pitot tube manometer, the pitot lines can be disconnected at the quick-connects on the Source Sampler Console.

External Vacuum Pump Unit

The External Pump Unit provides the vacuum that draws the sample from the stack. The pump assembly attaches to the Source Sampler Console by non-reversible 9.525-mm (3/8-inch) quick-connects and an electrical receptacle. Two interchangeable pump styles are available: the E-0523 lubricated rotary-vane pump; and the E-DAA dual diaphragm non-lubricated pump, with specifications shown in Table 1-2. The E-0523 is a rotary vane pump that requires lubrication. The pump is shipped from the factory without oil. Thus, the lubricator jar will need to be unscrewed and filled approximately ¾ full with lightweight lubricating oil (Gast AD220, SAE-10 or SAE-5). Both pump assemblies are available in either 120VAC or 240VAC operation. Please see Chapter 6 Maintenance and Troubleshooting for additional information on Apex Instruments pump units.

The External Pump Unit contains:

- The Vacuum Pump,
- Adjustable Lubricator (E-0523 only),
- Two (2) 1.524-m (5-ft) hose extensions with 9.525-mm (3/8-inch) quick-connects configured with male connector on the pressure side and female connector on the suction side,
- a rigid aluminum frame that protects the pump and allows easy access for service. A hinged, enclosure is available for either pump style.

Figure 1 - 3 Picture of E-0523 Lubricated Vane Vacuum Pump and optional E-DAA

Table 1 - 2 Features and Specifications of Apex Instruments Model MC-500 Series Vacuum Pumps

Model No.	Features
E-0523 **Standard Unit**	Lubricated Vane Pump Motor: 250 watts (1/3 hp), 120 VAC / 60 Hz, 1/2 Amp Measured Flow: 88 lpm @ 0.25 kPa (3.1 cfm @ 1 inch Hg); 42.5 lpm @ 3.73 kPa (1.5 cfm @ 15 inches Hg) Maximum Vacuum: 86.4 kPa (25.5 inches Hg) Weight: 15.9 kg (35 lb)
E-0523V	Optional 240 VAC / 50 Hz
E-DAA **Optional Unit**	Double Headed Diaphragm Pump Motor: 370 watts (1/2 hp), 120 VAC / 60 Hz, 1/2 Amp Measured Flow: 82 lpm @ 0.25 kPa (2.9 cfm @ 1 inch Hg); 40 lpm @ 3.73 kPa (1.4 cfm @ 15 inches Hg) Maximum Vacuum: 89.7 kPa (26.5 inches Hg) Weight: 13.6 kg (30 lb)
E-DAAV	Optional 240 VAC / 50 Hz

Probe Assembly

The Probe Assembly consists of the following:

- Probe Liner – 15.9mm (5/8in) OD tubing made from either Borosilicate Glass, Quartz, Stainless Steel, Inconel or Teflon®),
- Probe Heater - Removable rigid tube heater with coiled heating element, electric thermal insulation and thermocouple (Max Recommended Temperature: 260°C (500°F),
- Probe Sheath – 25.4mm (1in) OD tube with quad-assembly attached that includes a replaceable, modular S-type pitot tube, stack thermocouple and a 6.35-mm (1/4-inch) OD stainless steel tube to collect a gas sample for Orsat analysis,
- Small Parts Kit – Fittings to attach Nozzle to Probe Assembly. Fittings include: 15.9mm (5/8in) union, nut and ferrules along with o-rings and backer ring.

Figure 1-4 illustrates a standard Probe Assembly and a Probe Assembly with the optional 50.8mm (2in.) Oversheath and Packing Gland. The Figure 2.4 also details the connection between the nozzle and probe using fittings from the Small Parts Kit. Probe lengths vary from 0.914-m (3-ft) to 4.877-m (16-ft) nominal length. **Note:** Effective probe length in stack = 0.305-m (1-ft) less than nominal length.

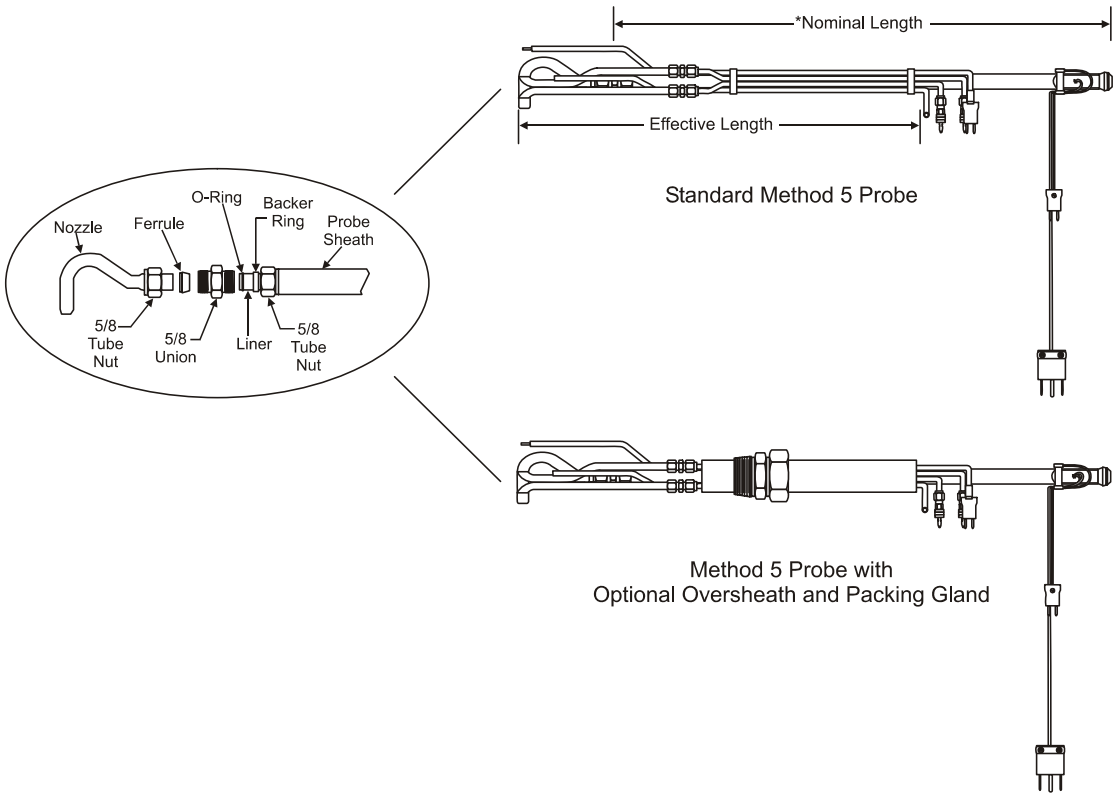


Figure 1 - 4 Diagrams of Probes and Probe Assembly

Probe Liner

Standard Probe Liners are constructed from 15.9mm (5/8in) OD tubing and have #28 ball joints attached. Liner materials available are borosilicate glass, quartz, stainless steel, inconel and Teflon®. Teflon® liners, straight liners and liners with integrated nozzles require a ball joint adapter. Various configurations are available, as shown below in Figure 1-5. Table 1-3 and Table 1-4 list the temperature limits for Probe Liner Materials and Probe Configurations, respectively.

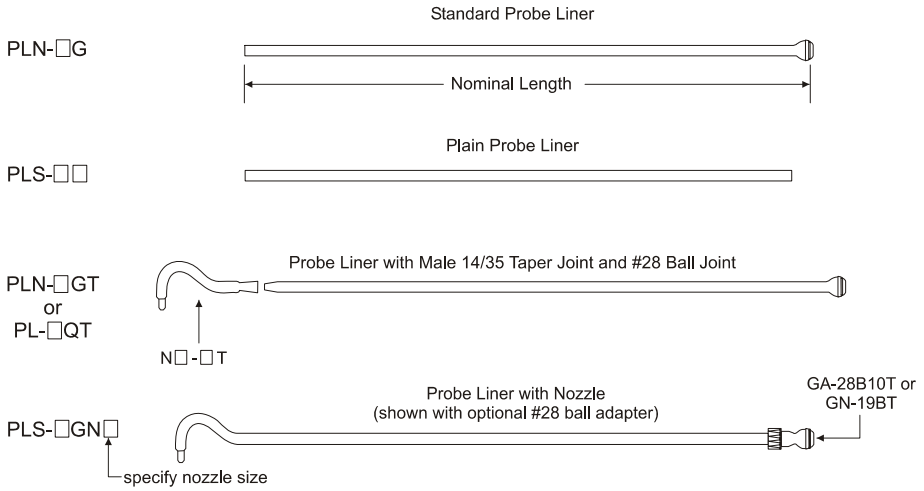


Figure 1 - 5 Diagrams of Probe Liner Configurations

Table 1 - 3 Maximum Stack Gas Temperatures for Probe Liner Materials

Material	Maximum Temperature
Teflon® Liners and Fittings	177°C (350°F)
Mineral-Filled Teflon® Fittings	315°C (600°F)
Borosilicate Glass Liners	480°C (900°F)
Stainless Steel Liners	650°C (1200°F)
Quartz Liners	900°C (1650°F)
Inconel Liners	980°C (1800°F)

Table 1 - 4 Probe Configuration Temperature Ratings

Probe Assembly Configuration	Maximum Temperature
Stainless Steel Sheath and Glass Liner	480°C (900°F)
Stainless Steel Sheath and Liner	650°C (1200°F)
Inconel Sheath and Liner	980°C (1800°F)
Inconel Sheath and Quartz Liner	980°C (1800°F)

Probe Heater

Apex Instruments Probe Heaters are designed to maintain the temperature of the sample traveling through the probe at 120°C ± 14°C (248°F ± 25°F). Our design features a rigid tube heater with coiled heating element, electrical thermal insulation with integrated thermocouple and power cord sealed in silicone-impregnated glass insulation. This mandrel-type heater design allows for liner replacement without removing the heating element. Standard heaters are configured for 120VAC operation and 240VAC configuration is available. The maximum recommended stack exposure temperature is 260°C (500°F). Exposure to elevated temperatures can damage the insulation and shorten the life of the heater. Table 1-5 lists the probe heater wattage required for probe nominal length.

Table 1 - 5 Probe Heater Wattage Requirements

Length, m (ft.)	Watts	Length, m (ft.)	Watts
0.914 (3)	325	2.74 (9)	475
1.22 (4)	350	3.05 (10)	500
1.52 (5)	400	3.35 (11)	525
1.83 (6)	400	3.66 (12)	550
2.13 (7)	400	4.27 (14)	600
2.44 (8)	450	4.88 (16)	600

Probe Sheath

Apex Instruments stainless steel Probe Sheaths feature a one inch diameter sheath constructed from corrosion-resistant stainless steel alloy, modular 3/8 inch pitot tip with ¼ inch stainless steel quick connects, stack temperature thermocouple and an orsat line. Inconel Sheaths are available for gas temperatures up to 1800°F.

Small Parts Kit

Apex Instruments Small Parts Kit (PK-SP) includes15.9mm (5/8in) union, nut and ferrules along with o-rings and backer ring as shown in Figure 1-4**.**

The Probe Assembly connects to the Modular Sample Case with the following connections:

- The probe sheath is mounted to the Modular Sample Case using a probe clamp that is attached to the probe holder of the sample case.
- Extending from the probe assembly is a thermocouple male connector, which connects to female thermocouple connector of the Umbilical Cable,
- An electrical plug connects to the electrical receptacle on the Modular Sample Case Hot Box.
- The outlet ball of the Probe Liner is inserted through the entry hole of the Filter Oven (Hot Box) compartment until the back of the sheath is even with the inside of the sample case.
- The pitot tube quick-connect lines, probe heater thermocouple, stack thermocouple and Orsat gas sample line are connected to the Source Sampler Console by the Umbilical Cable.

Modular Sample Case

The Modular Sample Case is used for support, protection and environmental control of the glassware in the sampling train. Figure 1-6 illustrates the major components and accessory connections on the Modular Sample Case. The Modular Sample Case consists of an insulated heated filter compartment (Hot Box) and insulated impinger case (Cold Box). The Hot Box features:

- Insulated (½ inch ceramic) filter box with dimensions 24 x 24 x 60 cm (9½ x 9½ x 23½ inches),
- 500-watt heating element,
- Oven thermocouple with external thermocouple receptacle,
- Dual access doors,
- Handle and SS bail clip monorail attachment,
- Removable stainless steel hinged probe clamp --19 cm length (7½ inches), and
- Stainless steel slides for connection/removal of impinger case.

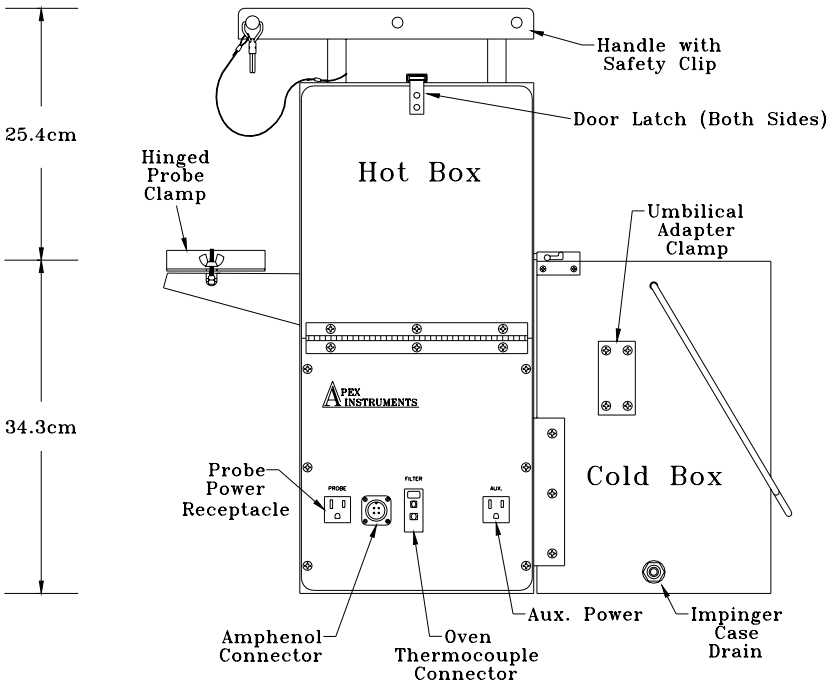


Figure 1 - 6 Modular Sample Case Components and Accessories.

The Cold Box holds the sampling train impingers in an ice bath so that the stack gas sample is cooled as it passes through the impingers to condense the water vapor. This enables measurement of stack gas moisture volume so that stack gas density can be calculated. Most testers have multiple Cold Boxes and sets of impingers for rapid turnaround between test runs. Cold Box features include:

- Durable polyethylene foam insulation plus pre-punched foam inserts for holding the impingers in place,
- Slide on/off guides plus spring-loaded latch to prevent accidental slippage,
- Fold down handle with rope centering guide,
- High-strength plastic bracket for supporting the Umbilical Adapter, and
- Four different removable insulated Cold Boxes (Impinger Cases) are available: SB-3 holds 4 impingers, SB-4 holds 8 impingers, SB-5 holds up to 14 impingers and the SB-3C accepts inexpensive removable liners. See Figure 1-7.

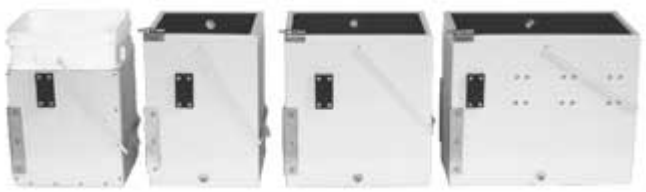
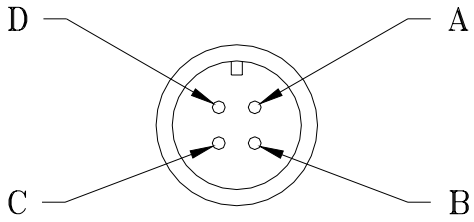


Figure 1 – 7: SB-3C Impinger Box Caddy, SB-3 Impinger Box, SB-4 Impinger Box, SB-5 Impinger Box

Umbilical Cable with Umbilical Adapter

The Umbilical Cable connects the Modular Sample case and Probe Assembly section of the isokinetic source sampling system to the Source Sampler Console. The Umbilical Cable contains:

- The primary gas sample line, 12.7-mm (½-inch) with male quick-connect to the Source Sampler Console and, at the opposite end, a 12.7-mm (½-inch) female quick-connect to the Umbilical Adapter.
- Two (2) pitot lines, 6.35-mm (¼-inch) with female quick-connects to the Probe Assembly and 6.35-mm (¼-inch) male quick-connects to the Source Sampler Console. The pitot lines are color-coded black and white for convenience.
- Another yellow line, 6.35-mm (¼-inch), which is intended for collecting a gas sample for Orsat analysis, can be used as a spare pitot line.
- Five (5) thermocouple extension cables for type K thermocouples, which terminate with full size connectors for durability. The connectors have different diameter round pins to maintain proper polarity, and will not fully connect if reversed. Each thermocouple extension wire in the Umbilical Cable is labeled and color-coded for temperature measurement of Stack, Probe, Oven (Hot Box), Exit (Cold Box), and Auxiliary (spare).
- AC power lines for the heaters in the filter compartment (Hot Box) and Probe Assembly. The power cable terminates with a circular connector (military style) connector on each end. The body of the circular connector is the ground conductor. A line-up guide is placed on each connector's end, and the retainer threads should be engaged for good contact. Figure 1-8 illustrates the circular connector with pins labeled.
- The Umbilical Cable is covered with a woven nylon mesh sheath to restrain the cable and reduce friction when moving the cable.
- The Umbilical Adapter connects the outlet of the glass impinger train to the Umbilical Cable and contains the exit thermocouple. This adapter serves as a strain relief between the Umbilical Cable and the glassware train.



A = Aux 120V/220V (Black)
B = Common (White)
C = Filter 120V/220V (Red)
D = Probe 120V/220V (Brown)

Figure 1 - 8 Circular Connector and Electrical Pin Designations.

Glassware Sample Train

The sample glassware train contains the filter holder for collection of particulate matter, glass impingers for absorption of entrained moisture, and connecting glassware pieces. Figure 1-9 illustrates the glassware of the USEPA Method 5 sampling train. The order in which a typical USEPA Method 5 glassware train is constructed is as follows:

1. Cyclone Bypass (GN-1) *Optional*: Cyclone (GN-2) and Cyclone Flask (GN-3)
2. 3 inch Glass Filter Assembly (GNFA-3). Assembly consists of the Filter Inlet (GN-3S), Teflon Filter Disk or "Frit" (GA-3T), Filter Outlet (GN-3B), Filter Clamp (GA-3CA) and Glass Fiber Filter (GF-3C).
3. Double "L" Adapter (GN-8)
4. 1st Impinger Modified Greenburg-Smith (GN-9A)
5. U-Tube (GN-11)
6. 2nd Impinger Greenburg-Smith with Orifice (GN-9AO)
7. U-Tube (GN-11)
8. 3rd Impinger Modified Greenburg-Smith (GN-9A)
9. U-Tube (GN-11)
10. 4th Impinger Modified Greenburg-Smith (GN-9A)
11. Sample Case/Umbilical Adapter (GA-100)

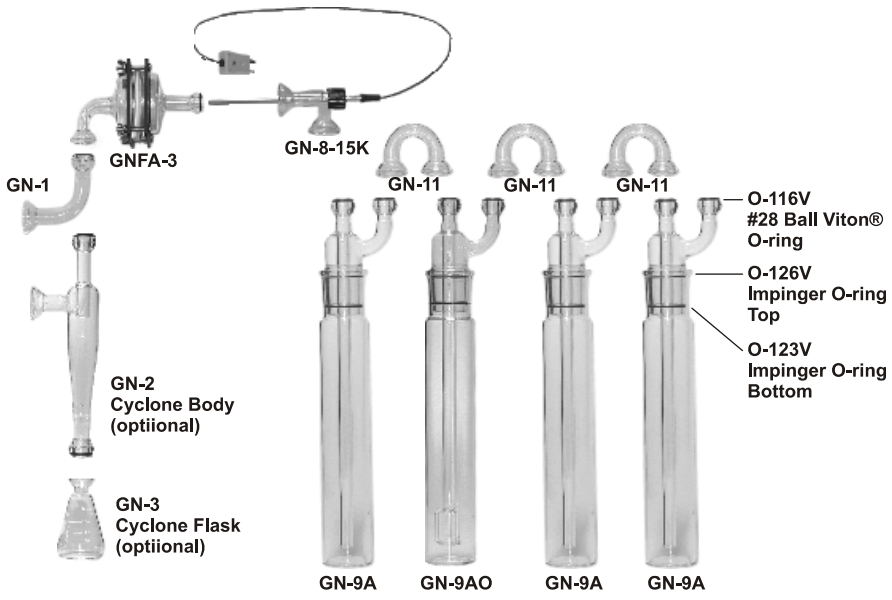


Figure 1 - 9 Glassware Sampling Train Schematic.

Chapter

2

Operating Procedures

There are many elements to consider before testing for particulate matter, which includes:

- Set up and check of source sampling system
- Test design
- Site preparation
- Sampling equipment calibrations (Described in Chapter 3)
- Assembling sampling equipment and accessories, reagents, sample recovery equipment, and sample storage containers
- Preliminary measurements of stack dimensions, gas velocity, dry molecular weight, and moisture.

Set-up and Check of Source Sampling System

Carefully unpack the contents, saving the packing material until the parts have been examined for shipping damage and the sampling system has been completely assembled. Check each item against the packing list. If any item is damaged or missing, notify Apex Instruments immediately at 800-882-3214 or email at info@apexinst.com. Appendix A lists the items in an Isokinetic Source Sampling System that are recommended for a system check.

Initial Set-up Procedure

These instructions are for a "dry run" set-up of the complete US EPA Method 5 sampling train. Do not load a glass fiber filter into the filter assembly, or charge liquids and silica gel in the impingers. The objective is to set-up the equipment to verify everything works.

1. Remove all items from packaging and place in an open area.

2. Slide the Impinger Case (Cold Box) onto the Modular Sample Case's heated filter compartment (Hot Box), using the steel slide guides. Check the fit and height of the Sample Case and Umbilical Adapter. The slides are adjustable for obtaining the desired fit. Engage the spring latch that locks the Cold Box into place.

3. Inspect the Probe Liner and Probe Assembly. Wipe clean the quick-connects on the Probe Assembly. A drop of penetrating oil helps keep the quick-connects in good working condition. Inspect the pitot tube openings for damage or misalignment, and, if necessary, replace or repair.

4. Slide the Probe Liner into the probe sheath. The plain end (no ball joint) of the liner should come out approximately 1.27-cm (1/2-inch) at the pitot tube end of the Probe Assembly.

5. Insert and tighten the Probe Assembly into the probe clamp that is attached to the Hot Box. The outlet ball of the Probe Liner is carefully inserted through the hole into the Hot Box and the back of the sheath is even with the inside of the Hot Box. Plug the Probe Heater electrical plug into the probe receptacle on the Hot Box.

6. To install a Nozzle to the Probe Assembly, consult Figure 2-1. Slide the ferrule system onto the plain exposed end of the Probe Liner. High temperature braided glass cord packing should be substituted for the o-ring when stack temperatures are >260°C (500°F). The Probe Assembly Spare Parts Kit (bag taped to probe sheath) contains fittings for two (2) different ferrule installation options: 1) Stainless Steel Single Ferrule, and 2) Backer Ring with O-Ring. The recommended configurations with different liner options are detailed below:

   a. Stainless Steel Liner — Stainless Steel Single Ferrule, or Backer Ring with O-Ring
   b. Glass Liner — Backer Ring with R-Ring, Teflon® Single Ferrule (Optional) Mineral-Filled Teflon® Single Ferrule (Optional).

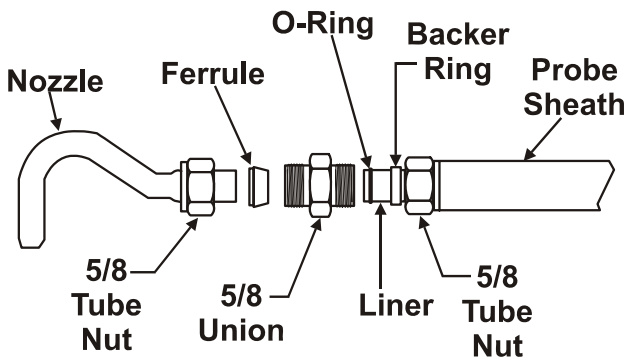


Figure 2 - 1 Installation of Probe Nozzle Connectors

7. Thread the 15.875 mm (5/8-inch) union onto the nut welded to the probe sheath. This is a compression fitting which is tapered to seal the ferrule system inserted on the Probe Liner. Tighten the fitting until the liner has a leak-tight seal, but DO NOT OVERTIGHTEN.

8. Connect the glassware sampling train completely in the Hot Box and Cold Box, and tighten all joints using the Ball Joint Clamps. The final connection is the Umbilical Adapter, which slides into the clamp on the outside of the Cold Box. Do not load the Filter Assembly with a filter, and do not fill the impingers because this is a "dry" set-up.

9. Connect the Umbilical Cable to the Modular Sample Case. Connect the Umbilical Cable circular connector plug to the receptacle on the side of the Hot Box (see Figure 1-6). Connect the labeled Umbilical Cable thermocouple plugs into the receptacles on the Hot Box, Probe Assembly, and Umbilical Adapter. Insert the Umbilical Cable sample line female quick-connect into the Umbilical Adapter male quick-connect. Insert the Umbilical Cable female pitot line quick-connects onto the Probe Assembly male quick-connects.

10. Connect the Umbilical Cable to the Source Sampler Console. Connect the Umbilical Cable circular connector plug to the receptacle on the front panel of the Source Sampler Console. Connect the labeled Umbilical Cable thermocouple plugs into the receptacles on the Source Sampler Console front panel. Insert the Umbilical Cable sample line male quick connect into the Source Sampler Console female quick-connect. Insert the Umbilical Cable pitot line male quick-connects onto the Source Sampler Console female quick-connects (labeled + and –). The pitot lines are colored to differentiate the positive and negative lines and keep the connections consistent between the pitot tube and Source Sampler Console.

11. Connect the Vacuum Pump Assembly to the Source Sampler Console. Wipe the quick connects clean then connect the pressure and vacuum hoses on the Vacuum Pump Assembly to the pump connections located on the lower left of the Source Sampler Console front panel. Connect the power cord of the Vacuum Pump Assembly to the receptacle on the Source Sampler Console labeled PUMP.

12. Plug the Source Sampler Console into an appropriate electrical power source.

System Check

Follow the set-up procedure in the previous section before starting system check procedure.

Initial Sampling System Leak Check

The system leak check is a "dry" run as described.

1. Close the Coarse Valve on the Source Sampler Console.

2. Insert a rubber stopper into the nozzle inlet.

3. Turn on the Vacuum Pump -- switch PUMP POWER ON.

4. Slowly open the Coarse Valve, and increase (fully close) the Fine Increase Valve.

5. The pump vacuum, as indicated on the Vacuum Gauge, should read a system vacuum within 10 kPa (3-in Hg) of the barometric pressure. For example, if the barometric pressure is 100-kPa (30-in Hg), then the Vacuum Gauge should read at least 92-kPa (27-in Hg).

6. Wait a few seconds for the pressure to stabilize. When the Orifice Tube pressure differential (ΔH) has returned to the zero mark, measure the leak rate for one minute, as indicated on the dry gas meter display. The observed leak rate should be less than 0.56 liters per minute (lpm) (0.02 cubic feet per minute (cfm)). If the leak rate is greater, check the tightness of all connections in the sampling train and repeat.

Test Design

Before testing, the operator should know the following:

- Why the test is to be conducted
- Who will use the data
- What stacks or emission points are to be tested and what process data is to be collected and correlated with test results
- Where the sample ports are located and type of access
- When the test is scheduled and deadlines for reporting
- How the method or procedure is followed, and how many test runs or process conditions will be tested

Site Preparation

Preparing the site so that sampling equipment can be positioned is frequently the most difficult part of sampling. When the sample ports do not have a platform or catwalk, then scaffolding must be erected to reach the sampling site. At many sites the operator must use his ingenuity to get the sampling equipment to the sample ports.

When selecting the site for sample ports, the operator should keep in mind that the distance form the probe to the bottom of the sample case is about 33 cm (13 ½ inches). This means that in traversing the stack, the sampling equipment needs 33 cm of clearance below the port level so as not to bump into guardrails or other structures. The dimensions needed for clearance along the sample port plane include the effective probe length (stack diameter plus port nipple length) PLUS at least 91 cm (36 inches) to accommodate the sample case (Hot Box, Cold Box, and probe clamp) length. Figure 2-2 illustrates the clearance zones required.

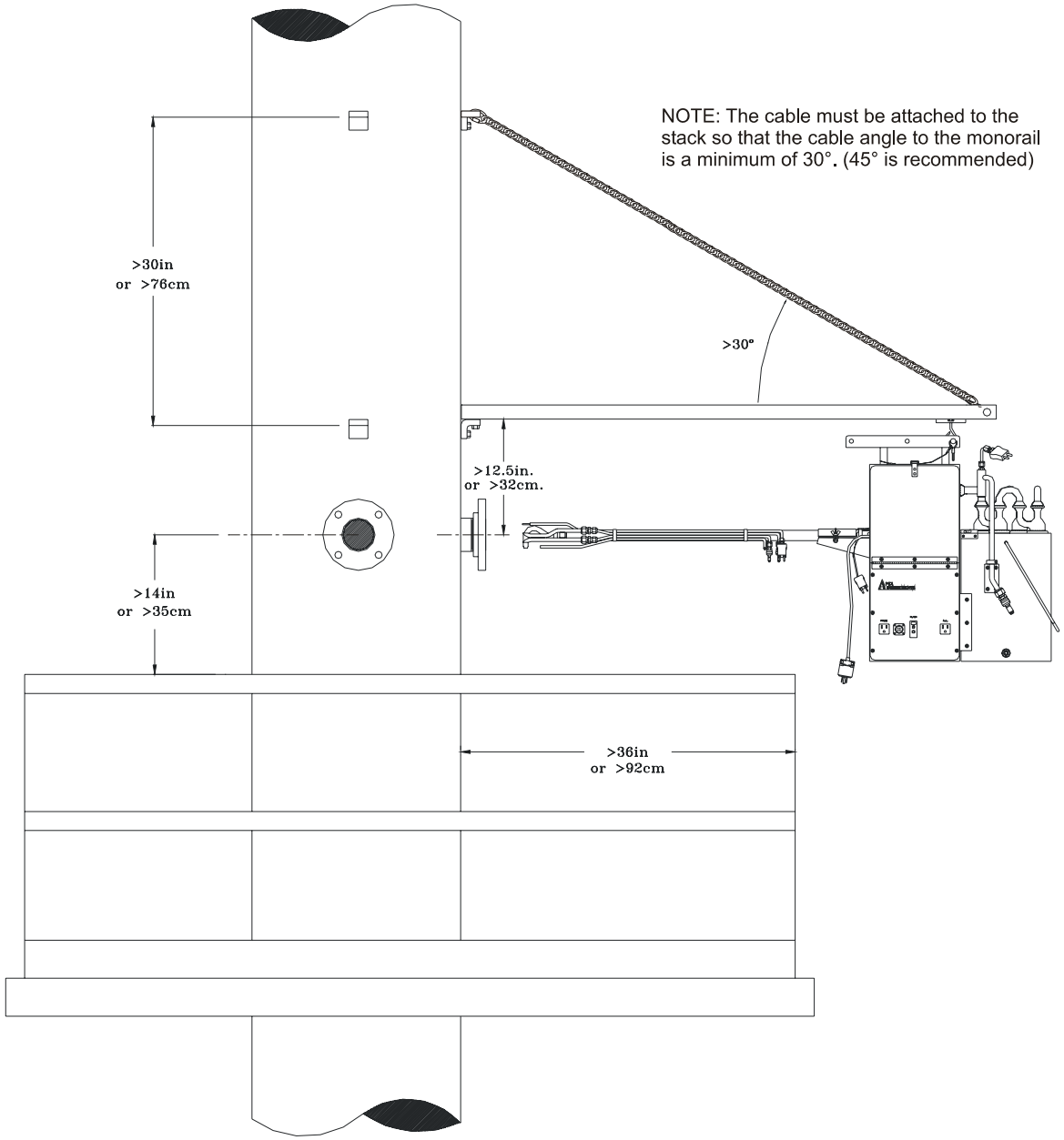


Figure 2-2 Clearance Zones at Stack for Isokinetic Sampling Train

Where sampling train clearance problems cannot be overcome, Apex Instruments offers a non-rigid Method 5 sampling train with separate and/or miniature heated Filter Box (SB-2M) to allow the Cold Box to be placed on the sampling platform connected by the sample line and Umbilical Adapter (GA-104). Another option is to use the Compact Method 5 with our Heated Filter Assembly (SFA-82H) and Power Box Adapter (UA-3J). Figure 2-3 illustrates the Non-Rigid Isokinetic Sampling Train. The midget hot box allows for less clearance between the monorail and guardrail of the stack. Figure 2-4 illustrates the Compact Method 5. The small heated filter assembly allows greater flexibility in small sampling areas.

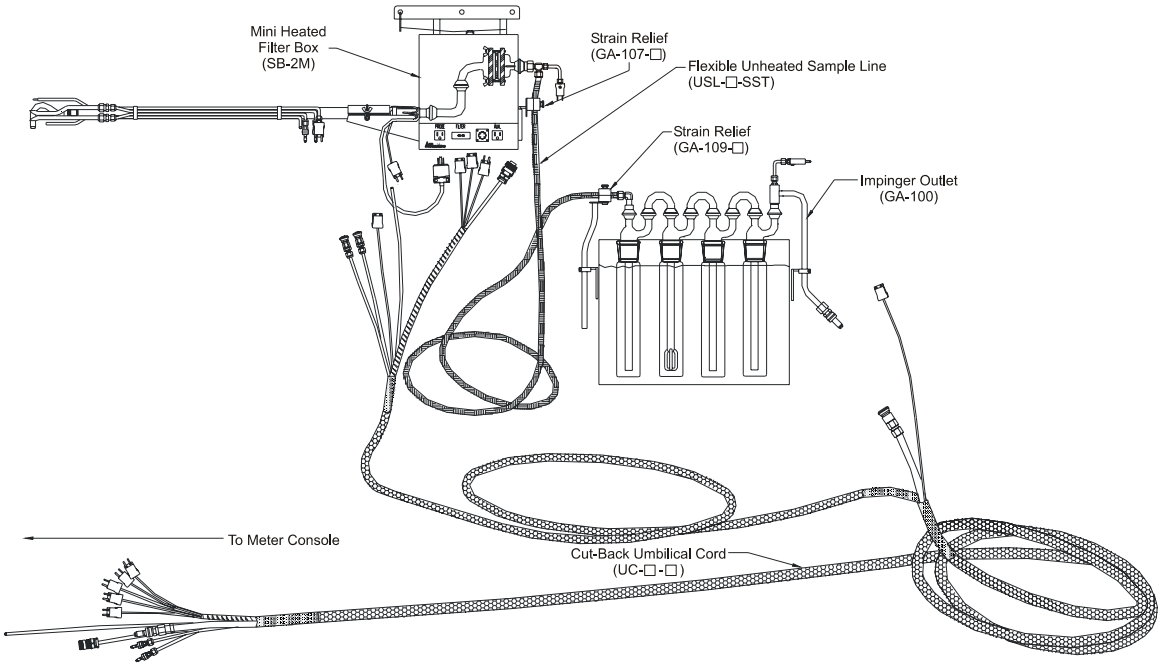


Figure 2-3 Schematic of Non-Rigid Isokinetic Sampling Train

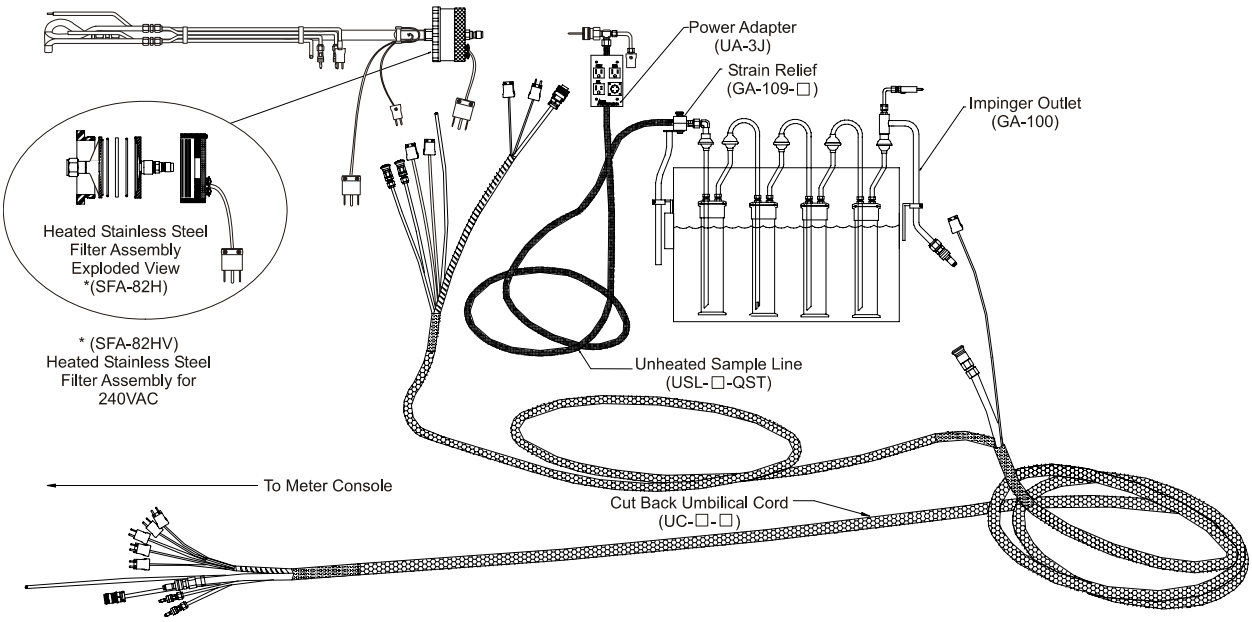


Figure 2-4 Schematic of Compact Isokinetic Sampling Train

Although the Isokinetic Source Sampling System was designed to fit into a 6.35 cm (2 ½ inch) sample port, 7.6 cm (3 inch) or larger holes allow easier entry and removal without damaging the nozzle or picking up deposited dust.

There are basically two ways to mount the isokinetic sampling system (Hot Box/Cold Box) for testing on a stack:

1. Assemble a monorail system with lubricated roller hook above each sample port, or
2. Construct a wooden platform slide apparatus (where feasible).

Figure 2-5 illustrates an isokinetic sampling system mounted on a monorail system above a sample port. When no mounting support for a monorail system exists, it can be easily fabricated using the Apex Instruments Monomount (P501) around the stack, as shown in Figure 2-6. Monorail mounting can be accomplished when an angle iron, with a hole or an eyehook, has been welded to the stack. Alternatively a tee bracket system such as that shown in Figure 2-5 may be used, with the load bearing calculations described. Figure 2-7 and Figure 2-8 illustrate a complete stack set-up using the Hot Box/Cold Box together (SB-1) and Hot Box and Cold Box separated (SB-3).

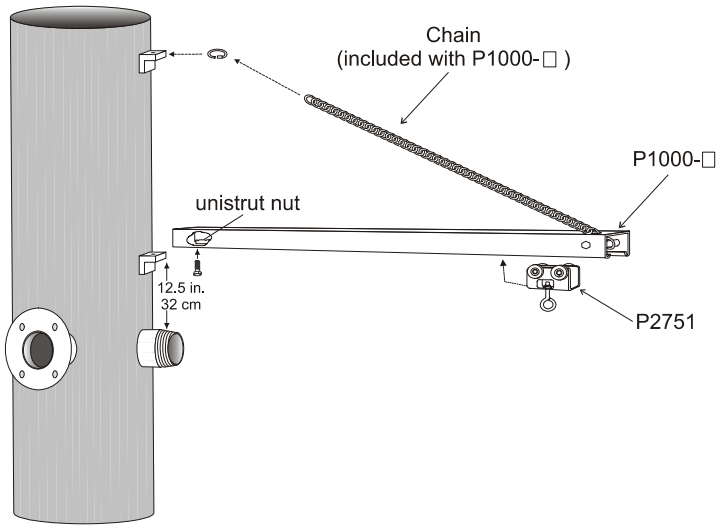


Figure 2-5 Illustration of Monorail System for Sampling Train

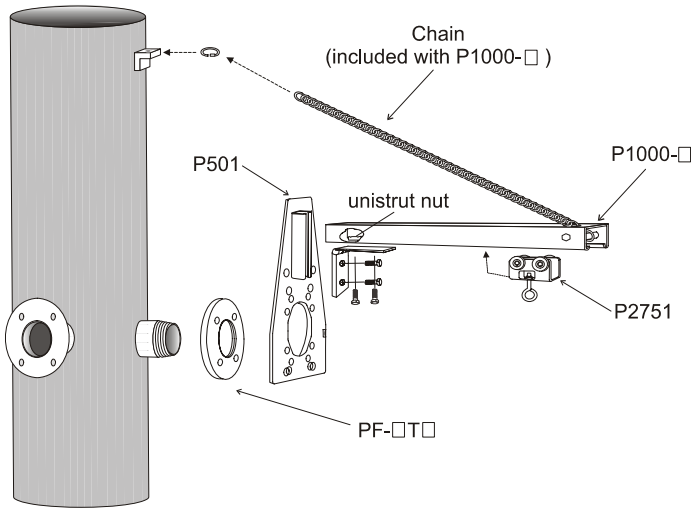


Figure 2-6 Illustration of Apex Instruments Monomount Monorail System

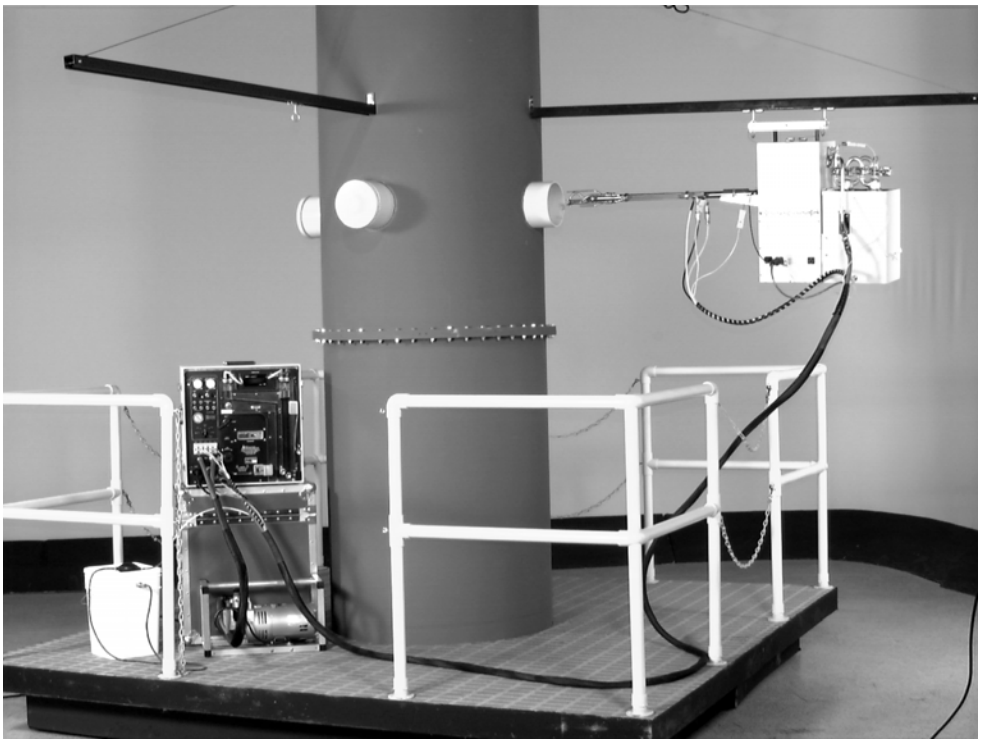


Figure 2-7 Stack Platform Set-up with Modular Sample Case on Monorail

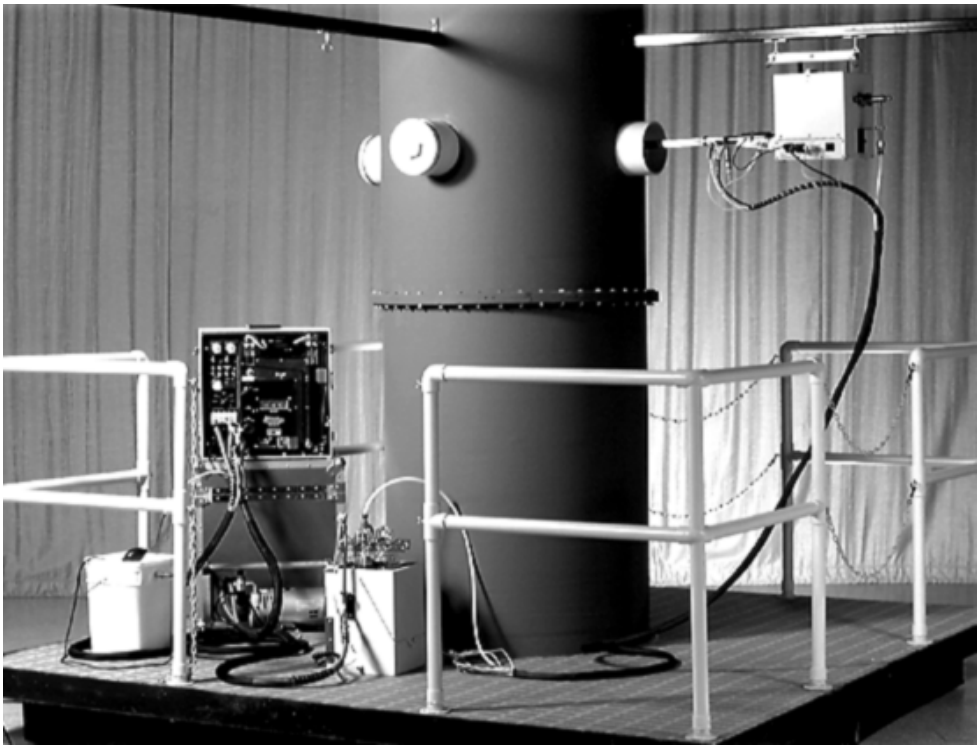


Figure 2-8 Stack Set-up with Hot Box on Monorail Separated from Cold Box

Assembling Sampling Equipment and Reagents

The use of checklists for assembling the sampling equipment, reagents and auxiliary supplies for a test is highly recommended. Appendix A contains the recommended equipment for isokinetic sampling. Appendix A also contains the recommended spare parts for isokinetic sampling, although not all of the list may be needed at a test site. Section 3 of USEPA Method 5 contains the list of reagents required to perform an isokinetic particulate test. A standard equipment and reagent checklist used by stack testers is provided in Appendix A.

Preliminary Measurements of Gas Velocity, Molecular Weight and Moisture

Before attempting to calculate the parameters needed for isokinetic sampling – probe nozzle size, ratio of $\Delta H/\Delta p$ (K factor) needed for isokinetic sampling rate, gas sample volume – several preliminary values are required:

Table 2-1 Preliminary Measurements for Isokinetic Sampling

No.	Symbol	Value Needed	Obtain from
1.	Δp_{avg}	Average stack gas velocity pressure head	1. Before the sample run (best), or 2. A previous test (often erroneous)
2.	P_s	Stack gas pressure	1. Before the sample run (best), or 2. A previous test (very small error)
3.	P_m	Dry gas meter pressure	Same as barometric pressure
4.	B_{ws}	Stack gas moisture fraction	1. Before the sample run (best), or 2. A previous test (often erroneous)
5.	T_s	Average stack gas temperature	1. Before the sample run (best), or 2. A previous test (often erroneous)
6.	T_m	Average dry gas meter temperature	Meter temperature rises above ambient because of pump heat and is typically estimated at 14°C (25°F) above ambient
7.	M_d	Stack gas molecular weight	1. Before the sample run (best), or 2. A previous test (very small error)
8.	$\Delta H_@$	Orifice meter calibration factor	Determined previously from laboratory calibration

USEPA Methods 1 through 4 are used to gather the preliminary values for Method 5 sampling. Then, when sampling using Method 5, the procedures of Methods 1 through 4 are completed to perform Method 5 sampling and calculations.

Method 1 – Determining Sample and Velocity Traverse Points

Method 1 is the first step towards collection of a representative sample for measuring particulate concentration and mass emission rate from a stack. The velocity and particle concentration in the stack are not uniform, so the cross-section must be traversed. The basic premise is that for straighter lengths of stack or duct, flow streamlines are more uniform and fewer traverse points are needed to obtain a representative sample. Conversely, the closer the sampling site is to bends and flow disturbances, the more traverse points are needed to obtain a representative sample. This method describes procedures to:

- Select an appropriate sampling location on the stack (if sample ports do not already exist)
- Calculate the number of traverse points for velocity and particulate sampling within the stack
- Calculate the location of the traverse points

Sampling sites are measured in terms of number of stack or duct diameters away from flow disturbances. Disturbances can be bends, transitions, expansions, contractions, stack exit to atmosphere, flames or presence of internal installations such as valves or baffles. Figure 2-9 depicts the relationship of stack diameters and a flow disturbance such as a bend.

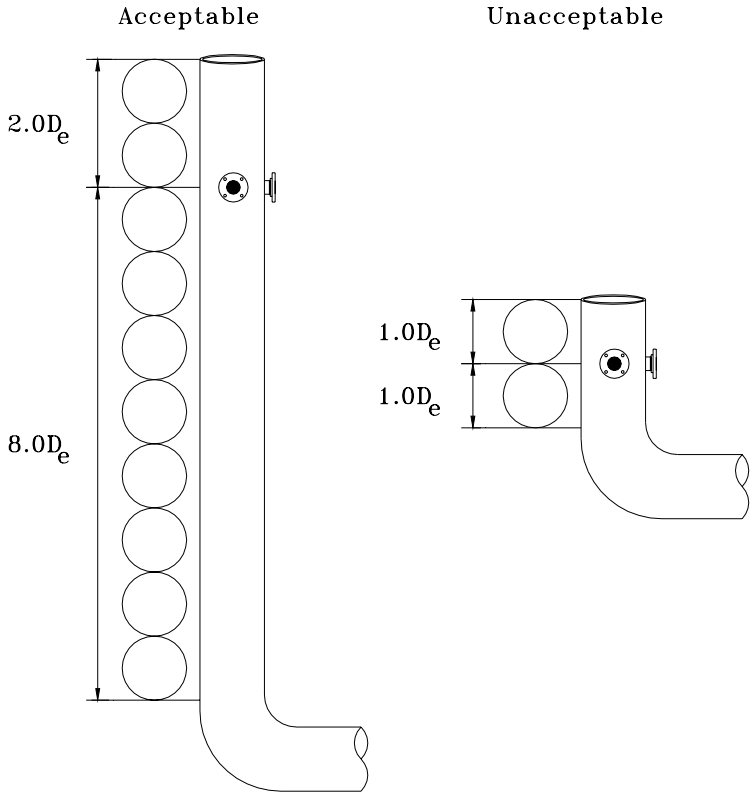


Figure 2-9 Visualizing Stack Diameters from Flow Disturbances

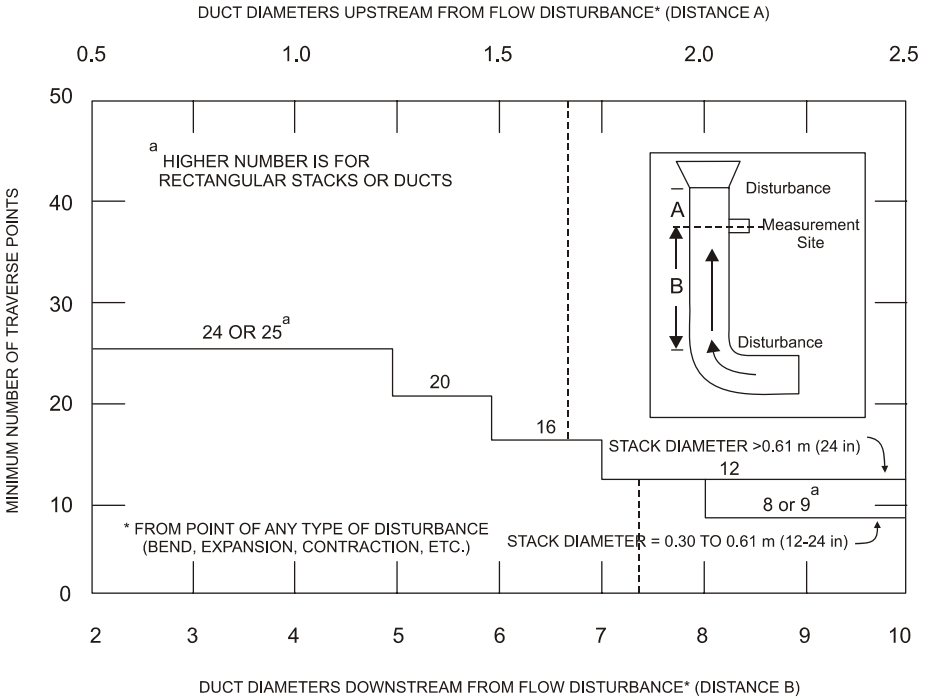
The procedure for calculating the minimum number of traverse points is as follows:

A) Measure the stack diameter to within 0.3175 cm (1/8 inch)
   1) Insert a long rod or pitot tub e into the duct until it touches the opposite wall.
   2) Mark the point on the rod where it meets the outside of the port nipple.
   3) Remove the rod, measure, and record this length to the far wall, L_{fw}
   4) With a tape measure (or rod if stack is hot), measure the distance from the outside of the port nipple to the near wall and record this length to the near wall, L_{nw}.
   5) Calculate the diameter of the duct from this port as $D = L_{fw} - L_{nw}$
B) Repeat for the other port(s) and then average the D values.
C) Measure the distance from the sample port cross-sectional plane to the nearest downstream disturbance (designated Distance A).
D) Measure the distance from the sample port cross-sectional plane to the nearest upstream disturbance (designated Distance B).
E) Calculate the number of duct diameters to the disturbances by dividing Distance A by D, and Distance B by D.
F) Use Figure 5 in Method 1 for particulate traverses (or Figure 12 for velocity traverses), determine where Distance A diameters meets the graph, then where Distance B diameters meets the graph, and select the higher of the two minimum numbers of traverse points.

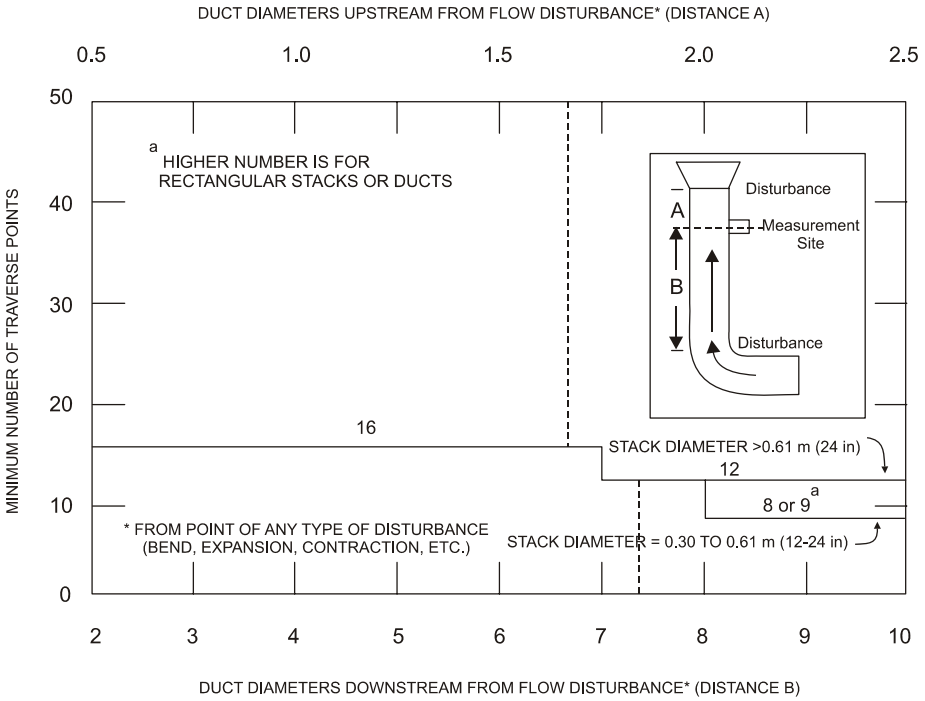
Tips from an Old Stack Tester

- *Measure the stack diameter from each sampling port – not all circular stacks are round! And not all rectangular stacks are perfectly rectangular.*
- *By Measuring in each port, we can often find in-stack obstructions and can check ourselves against erroneous measurements.*
- *If possible, shine a flashlight across the stack and check for obstructions or irregularities.*
- *If possible, with a glove on your hand, reach into the sampling port and check that the port was installed flush with stack wall (does not extend into the flow.)*

Figure 2-10 illustrates determining the total traverse point number from the curve of Method 1's Figure 1-1. For example, if Distance A is 1.7 duct diameters and Distance B is 7.5 duct diameters, then Distance A would indicate use of 16 traverse point and Distance B would indicate use of 12 traverse points. You must choose the higher of the two. Therefore, the sampling site requires 16 total traverse points, eight in each of two directions 90° apart.



(Minimum number of traverse points for particulate traverses.)



(Minimum number of traverse points for non-particulate traverses.)

Figure 2-10b Example of Determining Number of Traverse Points

For circular stacks with diameters greater than 60 cm (24 inches), the minimum number of traverse points required is twelve (12), or six (6) in each of two directions 90° apart, when the duct diameters from disturbances are eight (8) or more upstream and two (2) or more downstream. For circular stacks with diameters between 30 and 60 cm (12 and 24 inches), the minimum number of sample points required is eight (8), or four (4) in each of two directions 90° apart. For stacks less than 30 cm (12 inches) in diameter, refer to Method 1A for calculating traverse points.

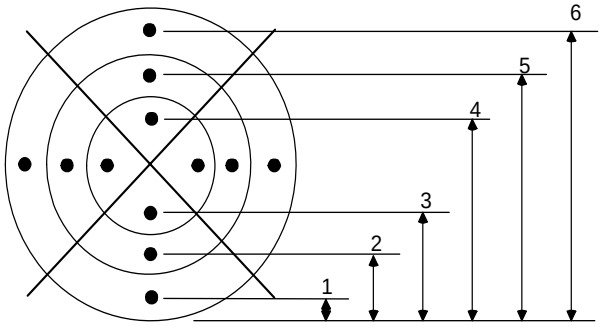
For rectangular stacks or ducts, an equivalent diameter must first be calculated using the following equation:

$$D_e = \frac{2LW}{L + W}$$

where D_e = equivalent diameter of rectangular stack
L = length of stack
W = width of stack

The minimum number of traverse points required for rectangular stacks is nine, or 3 x 3.
After the number of traverse points has been determined, the location of each traverse point must be calculated. The traverse points and their locations are designated as the sample point matrix. For circular stacks, the stack cross-section is divided into concentric rings of equal area based on the number of traverse points divided by four (4), the rings are bisected twice, and the sample points are located in the centroid (center of mass of each equal area, as shown in Figure 2-11. For rectangular stacks, the centroids are much easier to determine, as shown in Figure 2-12.

TRAVERSE POINT	DISTANCE % of diameter
1	4.4
2	14.6
3	29.6
4	70.4
5	85.4
6	95.6



This is an example of a circular stack cross section divided into 12 equal areas, with location of traverse points indicated.

Figure 2-11 Traverse Points Located in Centroids for Circular Stack

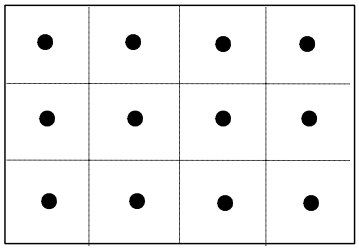
Table 2-2 Location of Traverse Points in Circular Stacks

(Percent of stack diameter from inside wall of traverse point)

Traverse point number on a diameter	***Number of traverse points on a diameter***				
	4	**6**	**8**	**10**	**12**
4	93.3	70.4	32.3	22.6	17.7
5		85.4	67.7	34.2	25.0
6		95.6	80.6	65.8	35.6
7			89.5	77.4	64.4
8			96.8	85.4	75.0
9				91.8	82.3
10				97.4	88.2
11					93.3
12					97.9

Table 2 - 3 Cross Section Layout for Rectangular Stacks

Number of Traverse Points	***Matrix Layout***
9	3 x 3
12	4 x 3
16	4 x 4
20	5 x 4
25	5 x 5
30	6 x 5
36	6 x 6
42	7 x 6
49	7 x 7



(This is an example of a rectangular stack cross section divided into 12 equal areas, with a traverse point at centriod of each area.)

Figure 2-12 Traverse Points Located in Centroids for Rectangular Stack

Tips from an Old Stack Tester

After calculating the traverse point locations (before adding sample port nipple length), you can check your work quickly by noticing if the first and last traverse point distances added together equal the stack diameter; then if the second and next to last; then if the third and third from last; and so on.

The procedure for locating each traverse point along the diameter for a circular stack and then marking the probe assembly or pitot tube is as follows:

- On a Method 1 field data sheet (data sheet can be computer or calculator generated) multiply the stack diameter by the percentage taken from the appropriate column of Table 2-2.
- Add the port nipple length to each value for each traverse point.
- Convert the decimal fraction to 1/8th (0.125) of an inch for each point (English units only).
- For stacks ≥ 60 cm (24 inches) in diameter, relocate any traverse points that are closer than 2.5 cm (1.00 inches) from the stack wall to 2.5 cm and label them as "adjusted" points. You may combine two successive points to form a single adjusted point, which must be sampled twice.
- For stacks, 60 cm (24 inches), do the same, except the adjusted distance is 1.3 cm (0.5 inch).
- Measure each traverse point location from the tip of the pitot tube, and mark the distance with heat-resistant fiber tape or whiteout correction fluid, as illustrated in Figure 2-13.

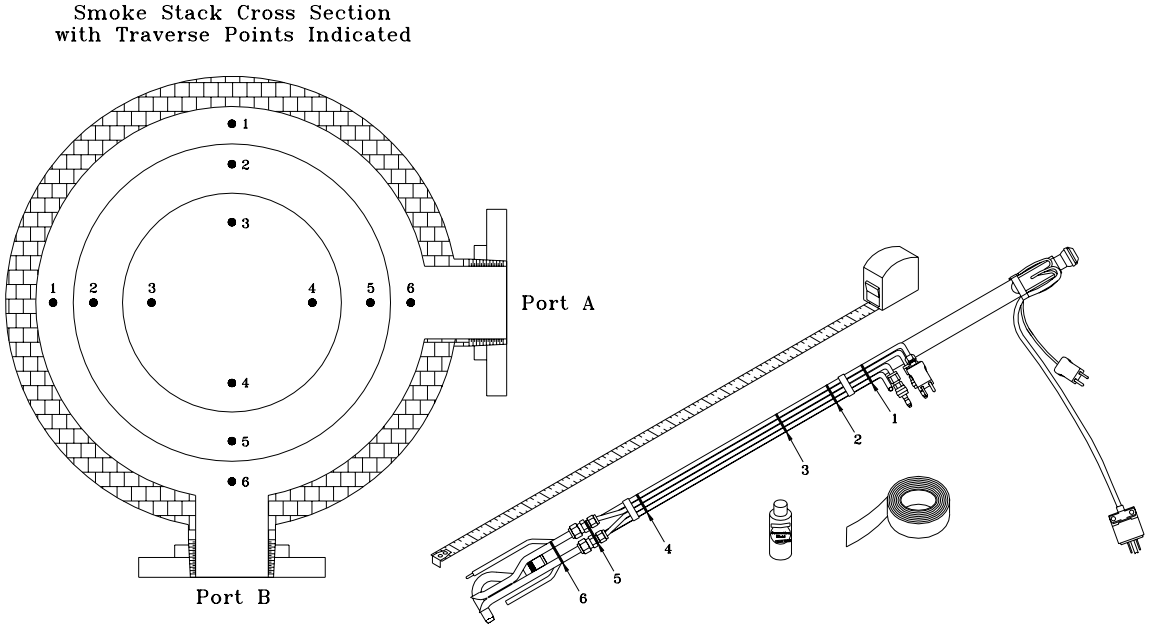


Figure 2-13 Illustration of Marking Traverse Points on Probe Assembly

Tips from an Old Stack Tester

"White-Out" correction fluid used on paper has amazing properties for stack testing. It dries quickly and withstands stack heat and moisture very well. To remove from a probe or pitot tube, simply scrape it off with your pocketknife. Various tapes and black marking pens do not hold up against stack conditions nearly as well.

Method 1A – Sample and Velocity Traverses for Small Stacks or Ducts

This procedure is the same as that in Method 1, except for the special provisions that apply to small stacks or ducts where 10.2 cm (4 in.) ≤ D ≤ 30.5 cm (12 in.), or for small rectangular ducts where 81.1 cm^2 (12.57 $in.^2$) ≤ A ≤ 729 cm^2 (113 $in.^2$). A standard type pitot tube must be used for the velocity measurements and must NOT be attached to the sampling probe. In these small diameter stacks or ducts, the conventional Method 5 stack assembly (consisting of a Type S pitot tube attached to a sampling probe equipped with a nozzle and thermocouple) blocks a significant portion of the duct's cross-section and causes inaccurate measurements. Therefore, for particulate matter sampling in small ducts, the gas velocity is measured either:

- Downstream of the sampling nozzle (for unsteady flow conditions), or
- In the same sample port alternately before and after sampling (for steady flow conditions).

The procedure for determining sampling location, traverse points, and flow rate (preliminary or other) in a small duct is as follows:

1. Select a site as shown in Figure 2-14.
2. Use Method 1 to locate traverse points for each site and choose the highest of the four numbers for traverse point number.
3. For PM (steady flow) or velocity (steady or unsteady flow) measurements, select one location and use the same criterion as Method 1.
4. For PM (steady flow) conduct velocity traverses before and after PM sampling to demonstrate steady state conditions, i.e., within ± 10% ($v_f/v_i \leq 1.10$).
5. For PM (unsteady flow), monitor velocity and sample PM at two separate locations simultaneously.

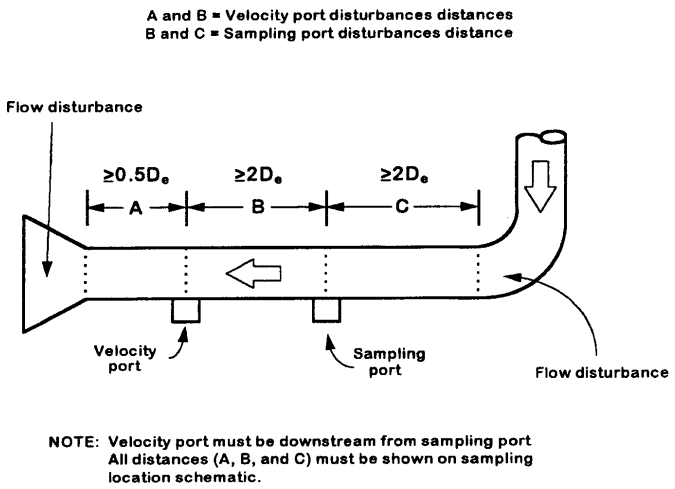


Figure 2-14 set-up of EPA Method 1A Small Duct Sampling Locations

Method 2 – Stack Gas Velocity and Volumetric Flow Rate

Method 2 is used to measure the average velocity and volumetric flow rate of the stack gas. There are two instances where Method 2 would be used:

- Prior to a particulate stack test series, to determine the size of the nozzle and length of the sampling run (preliminary velocity determination).
- During each stack test run, to ensure that the particulate sample is extracted from the stack at isokinetic conditions.

The equation for average gas velocity in a stack or duct is:

$$v_s = K_p C_p \left(\sqrt{\Delta p}\right)_{avg} \sqrt{\frac{T_{s(avg)}}{P_s M_s}}$$

Where v_s = Average stack gas velocity, m/sec (ft/sec)

Cp = Pitot tube coefficient, dimensionless

Δp = Velocity head of stack gas, mm H_2O (inches H_2O)

T_s = Absolute average stack gas temperature, °K (°R)

P_s = Absolute stack gas pressure, mm Hg (in. Hg)
$= P_{bar} + Pg/13.6$

P_{bar} = Barometric pressure at measurement site, mm Hg (in. Hg)

P_g = Stack static pressure, mm H_2O (in. H_2O)

M_s = Molecular weight of stack on wet basis, g/g-mole (lb/lb-mole)
$= M_d (1 - B_{ws}) + 18.0 B_{ws}$

M_d = Molecular weight of stack on dry basis, g/g-mole (lb/lb-mole)

K_p = Constant, 34.97 for metric system (85.49 for English system)

To obtain all values for input to the equation, values for molecular weight and moisture of the stack gas must be measured or estimated. Figure 2-15 illustrates the relationship of Methods 1,3 and 4 to Method 2.

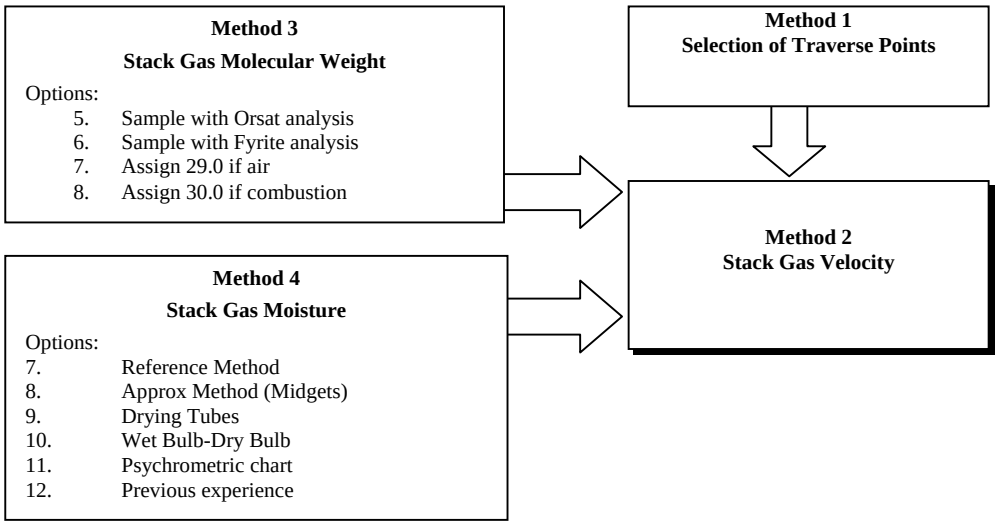


Figure 2-15 Determination of Preliminary Velocity

Velocity measurements in a duct are made using a pitot tube that is connected to an inclined manometer. Alternatively, a magnehelic pressure gauge or an electronic manometer can replace the inclined manometer, but each of these devices must be calibrated periodically against an oil-filled inclined manometer (see Section 4).

The S-type pitot tube is most often used in stack testing because:

- it is compact size makes it easy to attach to a Method 5 probe assembly,
- it is relatively easy to manufacture,
- it is relatively insensitive to plugging in stack gas streams,
- it is relatively insensitive to yaw and pitch errors, and
- it has a fixed pitot coefficient of 0.84 if manufactured and maintained to meet the geometric specifications of Method 2.

A standard or p-type (Prandl) pitot tube with coefficient = 0.99 can also be used for these measurements.

The S-type pitot tube is inserted into the stack, so that one leg (hole opening) of the pitot tube is pointing into the direction of gas flow, as shown in Figure 2-16. The leg pointing into the flow streamline measures impact pressure P_i, and the opposite leg pointing away from the flow measures wake pressure P_w of the gas stream. The velocity pressure Δp is the difference between the impact and wake pressures:

$$\Delta p = P_i - P_w$$

The procedure for determining flow rate (preliminary or other) in a stack gas stream is as follows:

1. Fill out the top section of a Velocity Traverse field data sheet.
2. Have the pitot tube marked for traverse points according to Method 1.
3. Assemble the apparatus for flow velocity measurement:
   a. Pitot tube with thermocouple, pitot and thermocouple extension lines, inclined manometer, temperature display deviceor
   b. Use Probe Assembly, Umbilical Cable and inclined manometer on Meter Console

4. Conduct a pre-test leak-check of the pitot and lines by blowing lightly into the positive (impact) side of the pitot tube opening until at least 7.6 cm (3 in.) H_2O registers on the manometer; then close off the impact opening; the pressure should remain stable for at least 15 seconds. Do the same, except suck lightly, for the negative (wake) side. If the pitot tube is dirty or chemically contaminated, attach a short piece of flexible tubing to the pitot leg for leak checking, and pinch off to hold the pressure.

5. Level and zero the manometer. If using a separate manometer, cup a hand or place a glove over the pitot opening to prevent wind from affecting the zero adjustment. If using the Source Sampler Console, use the Zero Manometer switch. Make periodic checks of zero and level between ports.

6. Insert the pitot tube into the stack to a marked traverse point, seal off the port opening with a rag or towel to prevent ambient effects. Measure the velocity head and temperature, and record on the field data sheet. It is suggested that the farthest point be measured first, and allow the temperature reading to stabilize.

7. Move to each traverse point, reseal the port, and record the velocity head and temperature. Switch to the next port and repeat traverse.

8. Conduct a post-test leak-check (mandatory to prove that no leakage occurred) as described in Step 4, and record on field data sheet.

9. Measure the static pressure in the stack. One reading is adequate.

10. Determine the barometric pressure at sample port level.

11. Calculate the average stack temperature from the traverse readings and record.

12. Calculate the average square root of velocity head by taking the square root of each velocity head reading and averaging the square roots (sum the square roots and then divide by number of traverse points), then record on the field data sheet.

It is important to ensure that the proper manometer or pressure gauge is being used for the range of Δp values encountered. If it is necessary to change to a more sensitive gauge, do so and remeasure the Δp and temperature readings at each traverse point, using the above procedures.

METHOD 2
VELOCITY TRAVERSE SET-UP

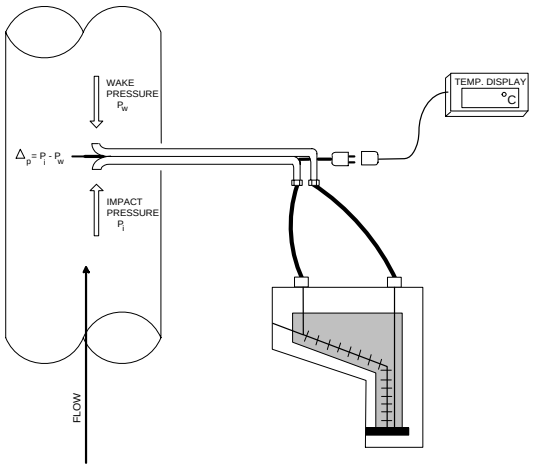


Figure 2-16 Apparatus for Preliminary Velocity Measurement

Static Pressure

Static Pressure can be measured any of three ways:

- Using a static tap,
- Using a straight piece of tubing and disconnecting one leg of the manometer.
- Using the S-type pitot tube and disconnecting one leg of the manometer, or

The easiest way is to use a piece of metal tubing inserted into the approximate middle of the stack, connected to a U-tube water-filled manometer with the other end open to atmosphere. If the manometer deflects toward the stack, it is recorded as negative static pressure (less than barometric pressure). If the manometer deflects away from the stack, it is recorded as positive static pressure. If an inclined manometer is used, then the connection to the tubing must be placed on the negative (right-hand) side of the manometer to read a negative static pressure and switched to the positive (left-hand) side to read a positive static pressure. If a stack static tap is used, the procedure is identical.

If an S-type pitot is used to measure static pressure, the following procedure will work:

1. Insert the S-type pitot tube into the stack near the middle.
2. Rotate the pitot about 90° until zero or null reading is obtained.
3. Holding the pitot in place, disconnect the positive side of the manometer and read the deflection of the oil in the manometer. Record the static pressure as negative.
4. If the oil travels past the zero mark, reconnect the positive side and disconnect the negative side, and read the deflection of the oil in the manometer. Record the static pressure as positive.

After the static pressure (Pg) is recorded, the value must be converted from mm H_2O to mm Hg (inches H_2O to inches Hg) prior to use in the velocity equation (as P_s). The density of mercury is 13.6 times that of water, so the conversion equation is:

$$P_s = P_{bar} + \frac{P_g}{13.6}$$

Barometric Pressure

The barometric pressure at the measurement site can be obtained by using a calibrated on-site barometer, or by contacting a local or nearby weather station (within 30 km) and obtaining the uncorrected station pressure (weather stations report barometric pressure corrected to sea level, so ask for the "uncorrected" pressure) and their elevation above sea level. You must also know the measurement site's elevation, and correct by subtracting 0.832 mm Hg for every 100 m rise in elevation (0.1 in. Hg for every 100 ft.). Calculate the sampling site barometric pressure, P_{bar}, as follows:

$$P_{bar} = P_r + 0.001(A - B)$$

where P_r = Barometric pressure at site ground level or at weather station, mm Hg (in.Hg)

A = Elevation at ground level or at weather station, m (ft. above sea level)

B = Elevation of the sampling site, m (ft. above sea level)

Stack Gas Molecular Weight and Moisture

To calculate the average stack gas velocity, values for the molecular weight and moisture must be obtained. See the sections on Method 3 and Method 4. The stack gas molecular weight dry basis (M_d) is corrected to the wet basis (M_s) using the moisture fraction (B_{ws}) by the equation:

$$M_s = M_d(1 - B_{ws}) + 18.0B_{ws}$$

After the average stack gas velocity (V_s) has been calculated, the volumetric flow rate can be calculated. The area of the stack (A_s) is calculated for circular stacks as:

$$A_s = \pi\left(\frac{D_s}{2}\right)^2$$

For rectangular stacks:

$$A_s = LW$$

The stack gas volumetric flow rate is calculated using the following equations:

$$Q_a = 60 v_s A_s$$

$$Q_s = K_s v_s A_s \frac{P_s}{T_s}$$

$$Q_{sd} = K_s(1 - B_{ws}) v_s A_s \frac{P_s}{T_s}$$

Where Q_a = Volumetric flow rate, actual, m^3/min (acfm)
Q_s = Volumetric flow rate, standard, sm^3/min (scfm)
Q_{sd} = Volumetric flow rate, dry standard, $dsmm^3$/min (dscfm)
K_s = Constant to convert time to minutes and P/T to standard conditions
= 21.553 for metric units (1058.8 for English units)

Method 3 – Gas Analysis for Dry Molecular Weight

Method 3 is used to measure the percent concentrations of carbon dioxide (CO_2), oxygen (O_2), and carbon monoxide (CO) if greater than 0.2%. Nitrogen (N_2) is calculated by difference. From this data, the stack gas dry molecular weight, or density, is calculated, and this data is used in the equation for stack gas velocity. From the gas composition data, the amount of excess air for combustion sources can be calculated. In jurisdictions where the particulate emissions are regulated on a concentration basis, such as mg/m3, the gas composition data can be used to correct the concentration results to a reference diluent concentration, for example 7% O_2 or 12% CO_2.

There are three options for determining dry molecular weight:

1. Sample and analyze,
2. Calculate stoichiometrically for combustion sources the O_2 and CO_2 concentrations, or
3. If burning fossil fuels (Coal, oil or natural gas), assign a value of 30.0 for dry molecular weight.

The stack gas sample can be collected using one of three options:

1. Grab sampling from a single traverse point a portion of the stack gas using a one-way squeeze bulb and loading directly into the analyzer. This technique can also be used to measure gas composition at individual traverse points to determine if stratification exists.
2. Integrated sampling from a single traverse point into a flexible leak-free bag. This technique recommends collection of at least 30 liters (1.00 cu. ft.); however, smaller volumes may be collected if desired. Constant rate sampling is used.
3. Integrated sampling from multiple points in a flexible leak-free bag. This technique is used when conducting a Method 5 particulate traverse and using the Orsat gas collection line built onto the Probe Assembly. Sample volume and rate recommendations are the same.

Gas samples can be analyzed using either an Orsat or Fyrite analyzer. Figure 2-17 depicts the options for sample collection and analysis.

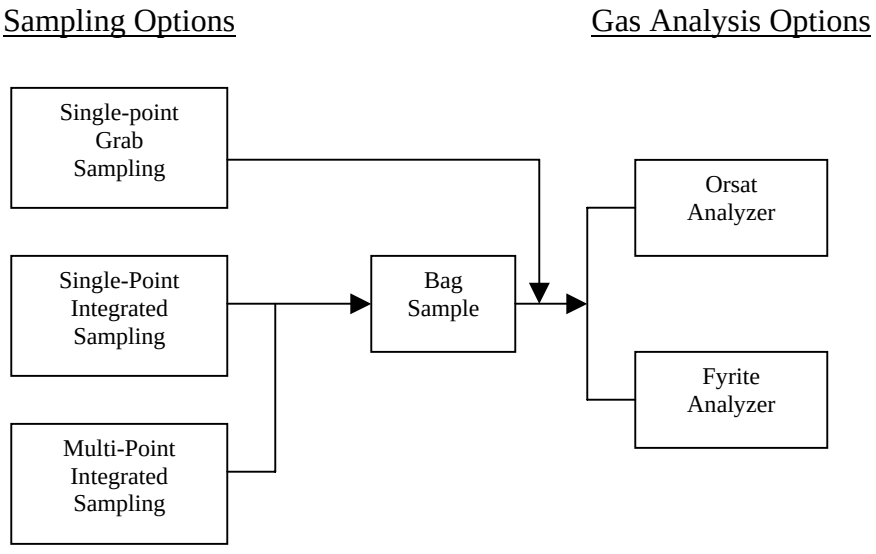


Figure 2-17 Sampling and Analysis Options of Method 3

Both the Orsat Analyzer and a Fyrite Analyzer are gas absorption analyzers, and measure the reduction in liquid volume when a gas sample is absorbed and mixed into a liquid solution. The Fyrite Analyzer uses separate gas absorption bulbs for O_2 and CO_2, while the Orsat Analyzer (Model VSC-33) contains all three absorption bubblers for O_2, CO_2 and CO in a single analyzer train. The Orsat provides a more accurate analysis of gas composition, and is required by Method 3B when pollutant concentration corrections are made for regulatory purposes. Figure 2-18 illustrates an Orsat Analyzer connected to a bag sample collection enclosure. The CO concentration is typically not measured by the Orsat analyzer for two reasons. First, the detection limit of the analyzer is 0.2% by volume (2,000 ppmv) which is well above most modern combustion source CO concentrations. Second, the molecular weight of CO is the same as N_2 (28 g/g-mole) and the balance of gas can be assumed to N2 without any change in calculation of molecular weight. For a more detailed discussion of gas analysis using an Orsat Analyzer, please refer to Apex Instruments' *Combustion Gas (ORSAT) Analyzer, Model VSC-33, User's Manual and Operating Instructions,* or the operating instructions provide with the Fyrite Analyzer.

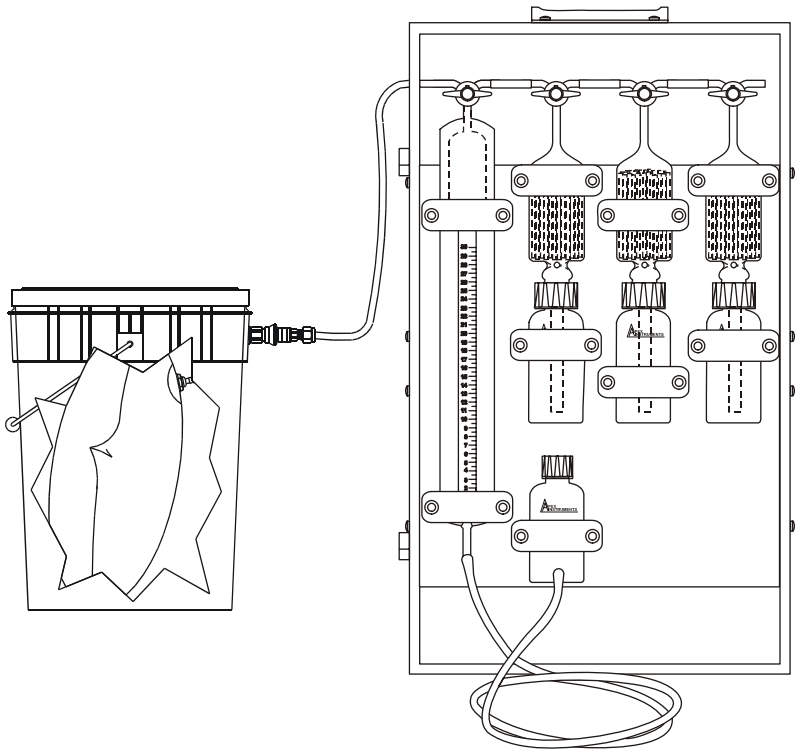


Figure 2-18 Illustration of Orsat Analyzer and Gas Sample Bag Container

The equation used to calculate dry molecular weight of a stack gas is:

$$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2 + \%CO)$$

Where
- $\%CO_2$ = Percent CO_2 by volume, dry basis
- $\%O_2$ = Percent O_2 by volume, dry basis
- $\%N_2$ = Percent N_2 by volume, dry basis
- %CO = Percent CO by volume, dry basis
- 0.28 = Molecular weight of N_2 or CO, divided by 100
- 0.32 = Molecular weight of O_2, divided by 100
- 0.44 = Molecular weight of CO_2, divided by 100

Method 4 – Moisture Content of Stack Gas

There are two separate procedures for determining moisture content in stack gases:

- The first is a Reference Method, for accurate measurements of moisture such as are needed to calculate emission data, and
- The second is an approximation method, which measures percent moisture to a good enough estimate to aid in setting isokinetic sampling rates prior to a pollutant emission run.

The approximation method is only a suggested approach. Alternative ways for approximating moisture content are also acceptable, for example:

- Wet bulb/dry bulb techniques (applicable to gas streams less than 100°C),
- Stoichiometric calculations (applicable to combustion sources),
- Condensation techniques,
- Drying tubes, and
- Previous experience testing at a stack

The Reference Method is almost always conducted simultaneously with a pollutant emission measurement run. The Reference Method is also used when continuous monitoring for pollutants, such as SO_2, NO_x or O_2 need to be corrected to a dry basis.

The equipment set-up for the Reference Method can consist of either of these sampling trains:

- The isokinetic source sampling system (Hot Box and Cold Box) equipped with Probe Assembly with no nozzle, and a filter bypass (GN-13) piece of glassware instead of a Filter Assembly (filter may be used if particulate levels are high), or
- The Basic Method 4 Test Kit includes a Cold Box, Sample Frame with Probe Clamp (SB-8), and Umbilical Adapter with power connector (GA-103), as shown in Figure 2-19. Either a standard heated Probe Assembly or a heated CEM probe (no pitot tube) can be used.

Although glass impingers are typically used as the condenser section in Method 4 and other isokinetic methods, they can be replaced with a stainless steel equivalent coil condenser (S-4CN) making a rugged and reliable system without the fragility of the traditional glass assembly.

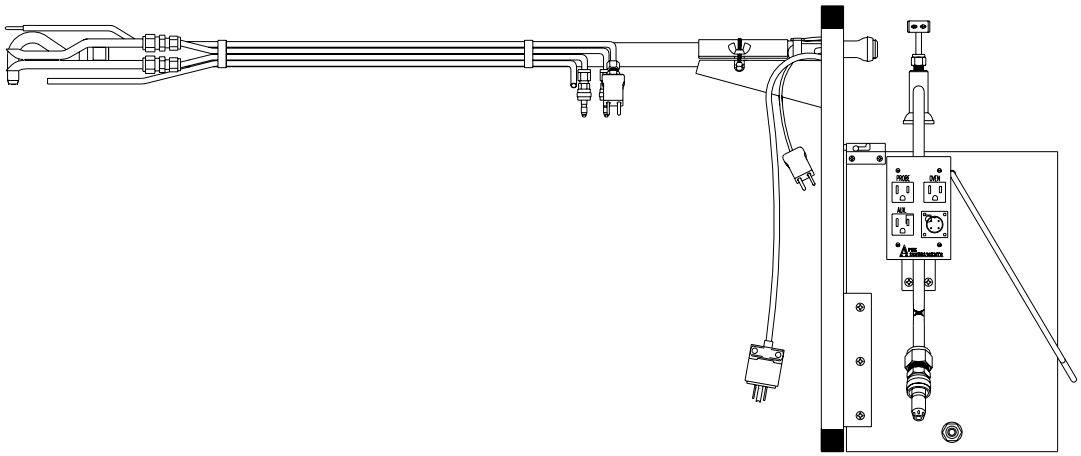


Figure 2-19 Set-up of Cold Box with Sample Frame and Probe Clamp

Reference Method 4

Use the following procedure for accurate measurements of moisture content:

A. Preparation

1. Use at least the following number of traverse points and locate them according to Method 1

   a) 8 for circular ducts <60 cm (24 inches) diameter

   b) 9 for rectangular ducts <60 cm (24 inches) equivalent diameter

   c) 12 for all other cases

2. Transfer about 100 ml of water into the first two impingers. Leave the third impinger empty, and weigh each impinger to ± 0.5 g.

3. Transfer about 200-300 g of silica gel into the fourth impinger, and weigh to ± 0.5 g.

4. Determine the sampling rate to collect ≥ 0.741 sm^3 (21scf) at ≤ 21 lpm (0.75 cfm) simultaneously with the pollutant emission rate test run (and for the same length of time).

5. If the gas stream is saturated or contains moisture droplets, attach a temperature sensor (± 1.3°C) to the probe or check the saturation moisture at the measured stack temperature. *See Section D.*

B. Sampling

1. Assemble and set up the sampling train.

2. Turn on the probe heater and (if applicable) the filter heating system to temperatures of about 120°C (248°F). Allow time for the temperatures to stabilize. Place crushed ice in the ice bath container (Cold Box) around the impingers.

3. ***Optional:*** Leak-check the sampling train from the inlet of the first impinger or, if applicable, the filter holder (see Leak-Check Procedure).

4. Position the probe tip at the first traverse point. Sample at a constant (± 10%) flow rate. Record data on a field data sheet.

5. Traverse the cross-section, sampling at each traverse point for an equal period of time.

6. Add more ice and, if necessary salt to maintain ≤ 20°C (68°F) at the silica gel impinger exit.

7. After the last traverse point of the cross-section, turn off the sample pump, switch to the next sample port, and repeat steps 2D through 2F.

8. At the completion of sampling, disconnect the probe from the first impinger (or from the filter holder).

9. ***Mandatory:*** Leak-check the sampling train as in step B3.

C. Sample Recovery

1. Disassemble the impinger glassware and weigh each impinger to ± 0.5 g. Record weighing data on a field data sheet.

2. Verify constant sampling rate.

3. Calculate the stack moisture percentage.

D. Saturated or Moisture Droplet-Laden Gases

1. Measure the stack gas temperature at each traverse point. Calculate the average stack gas temperature.

2. Determine the saturation moisture content by:

   a) using saturation vapor pressure tables or equations, or

   b) using a psychrometric chart and making appropriate corrections if stack pressure is different from that of the chart.

3. Use the lower of this value or the value from Section C.

Tips from an Old Stack Tester

Make sure to wipe off moisture from the outside of each impinger before weighing. Do not weigh with U-tubes connected.

Approximation Method

The Method 4 approximation method specifies use of midget impingers and a Source Sampler Console sized for midget impinger trains, such as that used for Method 6 for SO_2. Many stack testers perform preliminary moisture measurements for input to their isokinetic calculations nomograph by using a full-size sampling train and collecting about 0.283 sm^3 (10scf) of gas sample. These runs take about 15 to 20 minutes. Use the following procedures for approximate measurements of moisture content:

Midget Impinger Train

A. Preparation

1. Transfer about 5ml of water into each impinger (2), and weigh each impinger to ± 0.5 g. Assemble the sampling train.

2. Connect a pre-weighed drying tube to the back of impinger train.

B. Sampling

1. Assemble and set up the sampling train.

2. Turn on the probe heater and (if applicable) the filter heating system to temperatures of about 120°C (248°F). Allow time for the temperatures to stabilize. Place crushed ice in the ice bath container (Cold Box) around the impingers.

3. ***Optional:*** Leak-check the sampling train from the inlet of the first impinger inlet or, if applicable, the filter holder (see Leak-Check Procedures for non-isokinetic or isokinetic sampling trains).

4. Position the probe tip well into the stack. Sample at a constant (± 10%) flow rate of 2 lpm until about 0.031 m^3 (1.1 cf) or until visible liquid droplets are carried over from the first impinger to the second. Record initial and final data on a field data sheet.

5. Add more ice and, if necessary salt to maintain ≤ 20°C (68°F) at the silica gel impinger exit.

6. ***Mandatory:*** Leak-check the sampling train as in step B3.

C. Sample Recovery

1. Disassemble the impinger glassware and weigh each impinger or drying tube to ± 0.5 g. Record weighing data on a field data sheet.

2. Verify constant sampling rate.

3. Calculate the stack gas moisture percentage.

Large Impinger Train

A. Preparation

1. Transfer about 100ml of water into the first two impingers. Leave the third impinger empty, and weigh each impinger to 0.5 g.
2. Transfer about 200-300 g of silica gel to the fourth impinger, and weigh to 0.5 g.

B. Sampling

1. Assemble and set up the sampling train.
2. Turn on the probe heater and (if applicable) the filter heating system to temperatures of about 120°C (248°F). Allow time for the temperatures to stabilize. Place crushed ice in the ice bath container (Cold Box) around the impingers.
3. ***Optional:*** Leak-check the sampling train from the inlet of the first impinger inlet or, if applicable, the filter holder (see Leak-Check Procedures for non-isokinetic or isokinetic sampling trains).
4. Position the probe tip well into the stack. Sample at a constant (± 10%) flow rate of ≤21 lpm (0.75 cfm) until about 0.283 m^3 (10 cf). Record initial and final data on a field data sheet.
5. Add more ice and, if necessary salt to maintain ≤ 20°C (68°F) at the silica gel impinger exit.
6. ***Mandatory:*** Leak-check the sampling train as in step B3.

C. Sample Recovery

1. Disassemble the impinger glassware and weigh each impinger or drying tube to ± 0.5 g. Record weighing data on a field data sheet.
2. Verify constant sampling rate.
3. Calculate the stack gas moisture percentage.

To calculate the stack gas moisture content (B_{ws}), the following equations are used to compute the sample gas volume ($V_{m(std)}$) and gas moisture volume ($V_{wc(std)}$):

$$V_{m(std)} = K_3 Y \frac{V_m\left(P_{bar} + \frac{\Delta H}{13.6}\right)}{T_m}$$

where ΔH = Average orifice tube pressure during sampling, mm H_2O (in. H_2O)
V_m = Dry gas volume measured by dry gas meter, dcm (dcf)
T_m = Absolute temperature at dry gas meter, °K (°R)
Y = Dry gas meter calibration factor
K_3 = 0.3858 °K/mm Hg (metric units)
= 17.64 °R/in. Hg (English Units);

$$V_{wc(std)} = K_2(W_f - W_i)$$

where W_f = Final weight of water collected, g
W_i = Initial weight of water collected, g
K_2 = 0.001335 m^3/g (metric units)
= 0.04715 ft^3/g (English units); and

$$B_{ws} = \frac{V_{wc(std)}}{V_{m(std)} + V_{wc(std)}}$$

where B_{ws} = Proportion of water vapor, by volume, in the gas stream.

Method 5 – Determination of Particulate Emissions

There are several techniques for calculating the probe nozzle size and K-factor (ratio of $\Delta H/\Delta p$) needed for isokinetic sampling rate. These include:

- Calculating by hand or on a worksheet (see worksheets in Appendix D),
- Using a specially designed stack testing slide rule nomograph (M5A-1M or M5A-1), as shown in Figure 2-21.
- Using a pre-programmed hand held calculator (M5A-C), or
- Using a personal or laptop computer equipped with specialized spreadsheets for data collection and reduction (ISOCALC2.0) as shown in Figure 2-21.

Figure 2 - 21 Stack Sampling Sliderule and Laptop Computer with IsoCalc 2.2

The following preliminary information is first required to select the nozzle size and to calculate the K-factor:

- Average stack gas velocity head (Δp_{avg}). This is measured before the sample run, or from a previous test.
- Stack gas moisture fraction (Bws) or percent ($\%H_2O$). This may be determined from a preliminary run, previous test, or calculated (see Method 4).
- Stack gas dry molecular weight (M_d). This may be determined from a preliminary run, previous test, or estimated (see Method 3).
- Stack gas pressure (Ps). This is measured before the sample run, or if the static pressure of the stack is very low (sample ports near stack exit) the barometric pressure is used.
- Source Sampler Console orifice calibration factor ($\Delta H_@$). This is determined from the laboratory calibration and should be readily available on-site (see Calibrations).
- Meter temperature (T_m). Temperature at the meter rises about 14°C (25°F) above ambient temperature due to heat from the vacuum pump. The ambient temperature should be measured at the Source Sampler Console site.
- Meter pressure (Pm). Same as barometric pressure.

The equation most commonly used for calculating the probe nozzle size is:

$$D_{n(est)} = \sqrt{\frac{K_5 Q_m P_m}{T_m C_p (1 - B_{ws})} \sqrt{\frac{T_s M_s}{P_s \Delta p_{avg}}}}$$

where K_5 = 0.6071 (metric units)
= 0.03575 (English units)

After selecting the appropriate nozzle from the Nozzle Set, shown in Figure 2-22, the K-factor (ratio of ΔH/Δp such that ΔH = KΔp) used to maintain isokinetic sampling rate at each traverse point is calculated for the sampling test run using the following equation:

$$K = \frac{\Delta H}{\Delta p} = K_6 \, D_n^4 \, \Delta H_@ \, C_p^2 \left(1 - B_{ws}\right)^2 \frac{M_d \, T_m \, P_s}{M_s \, T_s \, P_m}$$

where D_n = Nozzle diameter, mm (inches)
T_m = Average DGM temperature, °K (°R)
T_s = Average stack gas temperature, °K (°R)
K_6 = 0.0000804 (metric units)
= 849.842 (English units)

The total sampling time (number of traverse points multiplied by minutes/point) as well as the final estimated gas sample volume ($V_{m(std)}$) should be checked against any applicable environmental regulations for the industry to see if minimum sampling times and volumes will be acceptable. The calculation may involve some iterations in selecting K-factors and/or nozzle size that will yield acceptable sampling volume and time.

Figure 2 - 22 Probe Nozzle Set

Method 5 Test Procedure

A. Pre-Test Preparation (Before Traveling to Site)

1. Check filters visually against light for irregularities and flaws or pinhole leaks. Label the filters on the back side near the edge using numbering machine ink.

2. Desiccate the filters at 20° ± 5.6°C and ambient pressure for ≥ 24 hr, and then weigh at intervals of ≥ 6 hr to a constant weight (≤ 0.5 mg change from previous weighing). Record results to ± 0.1 mg. During each weighing, do not expose the filter to the laboratory atmosphere for > 2 minutes and a relative humidity > 50%.

3. ***Optional:*** If condensable or back-half particulate matter is to be measured, run analytical blanks of the deionized/distilled water to eliminate a high blank on actual test samples.

4. Clean the Probe Liners and Probe Nozzles internally by brushing, first with tap water, then distilled/deionized water, followed by reagent-grade acetone. Rinse the Probe liner with acetone and allow to air-dry. Inspect visually for cleanliness and repeat the procedure if necessary. Cover the Probe Liner openings to avoid contamination. Nozzles should be kept in a case to avoid contamination or damage to the knife-edge. ***Note:*** Special cleaning procedures may be required for other test methods (for example, metals or dioxin).

5. Clean the Glassware (Filter Assemblies, Impingers and Connecting Glassware) internally by wiping grease from the joints, washing with glass cleaning detergent, rinsing with distilled/de-ionized water, followed by reagent-grade acetone, and then allow to air-dry. Cover all exposed openings with parafilm, plastic caps, serum caps, ground-glass stoppers or aluminum foil (not for metals!) to avoid contamination. ***Note:*** Special cleaning procedures may be required for other test method (for example, metals or dioxin).

B. Preliminary Determinations

1. Select the sampling site, measure the stack or duct dimensions, and determine the number of traverse points (see Method 1)

2. Determine the stack gas pressure, range of velocity pressure heads, and temperature (see Method 2)

3. Select the proper differential pressure gauge (see Method 2).

4. Determine or estimate the dry molecular weight (see Method 3).

5. Determine the moisture content (see Method 4).

6. Select a suitable Probe Assembly length such that all traverse points can be sampled.

7. Select a nozzle size and determine the K-factor for isokinetic sampling rate. ***Note:*** *Do* ***NOT*** *change nozzle size during the sampling run.*

8. Select the total sampling time and standard gas sample volume specified in the test procedures for the specific industry. Select equal sampling times of ≥ 2 minutes per traverse point.

C. Preparation of Sampling Train

1. Mark the Probe Assembly with heat-resistant tape or "White-Out" to denote the proper distance into the stack or duct for each sampling point.

2. Insert the Probe Nozzle into the probe sheath union, and finger tighten the union fitting. Avoid over tightening to prevent cracking the glass probe liner. Keep the nozzle tip and the ball joint on the glass probe liner covered until the assembly of the train is complete and sampling is about to begin. Secure the Probe Assembly to the Sample Case by tightening the probe clamp.

3. Prepare each set of impingers for a sampling run

   a) Impingers 1 & 2: 100 ml water in each
   b) Impinger 3: Empty
   c) Impinger 4: 200 to 300 g of silica gel

Note: More than one sampling run can be prepared with multiple sets of glassware!

4. Weigh each impinger to the nearest ± 0.5 g using a top-loading electronic balance (BAL-1200) and record initial weights on a field data sheet.

Figure 2-23 Top-Loading Electronic Balance

5. Assemble the impingers in the Cold Box with U-tubes, Double "L" Adapter, and the Sample Case/Umbilical Adapter, using Ball Joint Clamps or Clips.

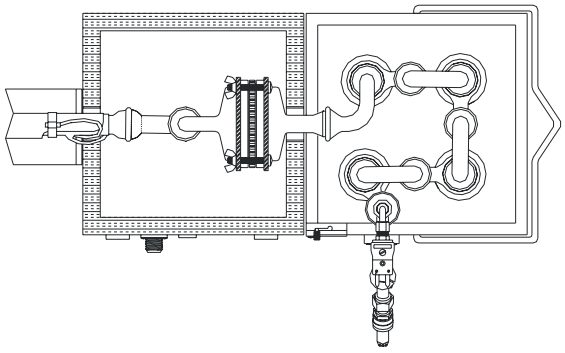


Figure 2-24 Top View of Assembled Impingers

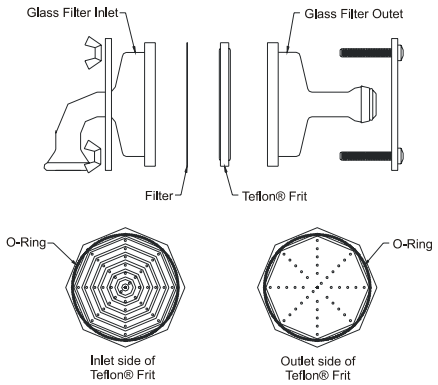


Figure 2-25 Exploded View of Filter Assembly

6. Using tweezers or clean disposable surgical gloves, place the tared filter on the grooved side of the TFE filter support in the Filter Holder. Check the filter for tears after placement, and center on the filter support. Assemble the Filter Holder and tighten the clamps around the Filter Holder to prevent leakage around the O-ring. Record filter number on the field data sheet.

7. Connect the Filter Holder and Cyclone Bypass (GN-1) in the Hot Box to the Probe Liner ball joint and to the "L" Adapter using Ball Joint Clamps. Close the Hot Box doors and fasten shut.

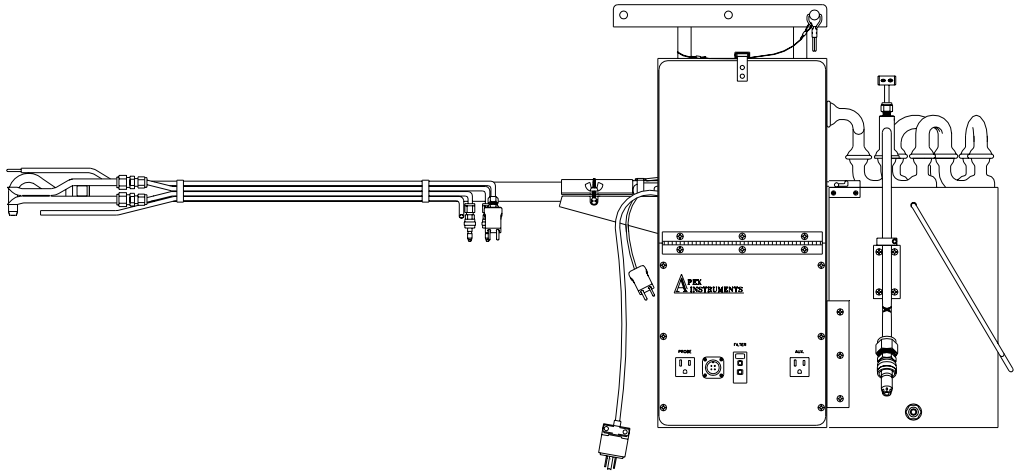


Figure 2-26 Assembled Sampling Train Before Umbilical Hookup

8. Connect the Umbilical Cable electrical and pitot tube line connections to the assembled sampling train and to the Source Sampler Console. If used, connect the Orsat line also.

9. Place the assembled sampling train near the first sample port, either on the monorail or other support.

10. Turn on and set probe and Hot Box heaters. Allow the Hot Box and probe to heat for at least 15 minutes before starting the test, and make periodic checks and adjustments to ensure the desired temperatures. Check all thermocouple connections by dialing through each selection and noting ambient or heated temperatures. Place crushed ice and a little water around the impingers.

11. Optional: Leak-check the sampling train (see Leak-Check Procedure for Isokinetic Sampling Trains in Method 4 and Pitot Tube and Line Leak-Check in Method 2).

D. Sampling Run Procedure

1. Open and clean the portholes of dust and debris

2. Level and zero the Δp and ΔH manometers

3. Record data on a field data sheet. Record the initial dry gas meter (DGM) reading.

4. Remove the nozzle cap, verify that the Hot Box/filter and probe heating systems are up to temperature, and check pitot tube, temperature gauge, and probe alignments and clearances.

5. Close the Coarse Valve and fully open the Fine Increase Valve. Position the nozzle at the first traverse point. Record the clock time, read Δp on the manometer and determine ΔH from the nomograph. Immediately start the pump, and adjust6 the flow to set the ΔH, first by adjusting the Coarse Valve and then the Fine Increase Valve. ***Note:*** If necessary to overcome high negative stack pressure, turn on the pump while positioning the nozzle at the first traverse point.

6. When the probe is in position, block off the openings around the probe and porthole using duct tape, rags, gloves or towels (or flameproof materials for hot stacks).

Figure 2-27 Blocking off the Porthole During Sampling

7. Record the ΔH, pump vacuum and temperatures for stack gas, DGM, filter box, probe, and impinger exit. Record the ID numbers for DGM, thermocouples, pitot tube, and Sample Box.

8. If simultaneously running Method 3 gas bag collection, turn on the Orsat pump. Turn Orsat pump off during port changes.

9. Traverse the stack cross-section for the same time period at each point without turning off the pump except when changing ports. *Do not bump the probe nozzle into the stack walls.*

a) Maintain the temperature of the Hot Box (probe outlet or filter outlet) at the proper level.

b) Monitor the Δp during each point, and if the Δp changes by more than 20%, another set of readings should be recorded.

c) Periodically check the level and zero of the manometers, and re-adjust if necessary.

d) Record DGM readings at the beginning and end of each sampling time increment, before and after each leak-check, and when sampling is halted.

e) Take other readings (ΔH, temps, vacuum) at least once each sample point during each time increment, maintaining the ΔH/Δp isokinetic ratio.

f) Add more ice and, if necessary, salt to maintain a temperature <20°C (68°F) at the silica gel impinger exit.

10. At the end of the sample run, turn off the Coarse Valve, remove the probe and nozzle from the stack, turn off the pump and heaters, and record the final DGM reading.

11. ***Mandatory:*** Leak-Check the sampling train at the maximum vacuum achieved during the sample run. Record leak-check results on field data sheet.

12. ***Mandatory:*** Leak-Check the pitot lines. Record on the field data sheet.

13. Allow the probe to cool. Wipe off all external particulate material near the tip of the probe nozzle, and cap the nozzle to prevent contamination or loss of sample. *Hint:* Open the Hot Box doors to allow the filter holder to cool.

14. Before moving the sampling train to the cleanup site, disconnect the probe from the Cyclone Bypass inlet and cover both ends. Do not lose any condensate that might be present. Disconnect the Filter Holder from the "L" Adapter and cap off the Filter Holder.

15. Disconnect the Umbilical Cable from the Sample Box and cover the last impinger outlet and first impinger inlet. Disconnect the Cold Box from the Hot Box. The Probe/nozzle Assembly, Filter Holder, and impinger case are ready for sample recovery.

16. Transfer the probe and filter-impinger assembly to a cleanup area that is clean and protected from the wind.

E. Variations and Alternatives

1. Acceptable alternatives to glass probe liners are metal liners, for example, 316 stainless steel, Inconel or other corrosion resistant metals made of seamless tubing. These can be useful for cross-sections over 3 m (10 ft.) in diameter. Whenever practical, make every effort to use borosilicate glass or quartz probe liners. Metal liners will bias particulate matter results high.

2. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probe.

3. Use either borosilicate or quartz glass probe liners for stack temperatures up to 480° to 900°C (900 – 1,650°F). The softening temperature for borosilicate glass is 820°C (1,508°F), and for quartz it is 1,500°C (2,732°F).

4. Rather than labeling filters, label the shipping containers (glass or plastic petri dishes), and keep the filters in these containers at all times except during sampling and weighing.

5. Use more silica gel in impinger 4, if necessary, but ensure that there is no entrainment or loss during sampling. Hint: Loosely place cotton balls or glass wool in the neck of the silica gel impinger outlet stem.

6. If a different type of condenser (other than impingers) is used, measure the amount of moisture condensed either volumetrically or gravimetrically.

7. For moisture content, measure the impinger contents volumetrically before and after a sampling run. Use a pre-weighed amount of silica gel in a shipping container, then empty the silica gel after the run back into the container for weighing at another time.

Figure 2-28 Recovering Silica Gel for Weighing

Figure 2-29 Determining Moisture Volumetrically

8. If the total particulate catch is expected to exceed 100 mg or more or when water droplets are present in the stack gas use a Glass Cyclone between the probe and Filter Holder.

9. If high pressure drops across the filter (high vacuum on the gauge) causing difficulty in maintaining isokinetic sampling, replace the filter. Suggestion: Use another filter assembly rather than changing the filter itself. Before installing a new filter, conduct a leak-check. Add the filter assembly catches for the total particulate matter weight.

10. Use a single train for the entire sampling run, except when simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or in cases where equipment failure necessitates a change in trains. In all other situations, obtain approval from the regulatory agency before using two or more trains.

11. When two or more trains are used, analyze separately the front-half and (if applicable) impinger catches from each train unless identical nozzle sizes were used on all trains. In this case, the front-half catches may be combined (as may the impinger catches) and one analysis of front-half catch and one analysis of impinger catch may be performed. Consult with the regulatory agency for details concerning the calculation of results when two or more trains are used.

12. If a flexible line is used between the first impinger or condenser and the Filter Holder, disconnect the line at the Filter Holder, and let any condensed water or liquid drain into the impingers or condenser.

13. Do not cap off the probe tip too tightly while the sampling train is cooling down, as this would create a vacuum in the Filter Holder, which may draw water from the impingers into the Filter Holder.

F. **Sample Recovery**

Sample Recovery is extremely important because that is where sample loss can occur (bias results low due to sampler errors or blunders) or contamination can be introduced (bias results high).

1. Place 200 ml of acetone from the wash bottle being used for cleanup in a glass sample container labeled “Acetone Blank”.

2. Inspect the train prior to and during disassembly, and note any abnormal conditions on the data sheet.

3. Container No. 1 – Filter

a) Using a pair of tweezers (TW-1) and/or clean disposable surgical gloves, carefully remove filter from the Filter Holder, and place it in its identified petri dish container. If necessary, fold the filter such that the particulate matter cake is inside the fold.

b) Using a nylon bristle brush (DB-3) and/or a sharp-edged blade (LS-1), carefully transfer to the petri dish any PM and/or remaining pieces of filter or filter fibers that adhere to the filter support or gasket.

4. Container No. 2 – Acetone Rinses – Recover any particulate matter from the internal surfaces of the Probe Nozzle, swaged union fitting, probe liner (use a glass funnel to aid in transferring liquid washed to the container), front half of the Filter Holder, and (if applicable) the cyclone, and recover all rinses in a single glass container as follows:

a) Before cleaning the front half of the Filter Holder, wipe clean all joints of silicone grease.

b) Rinse with acetone, brush with small nylon bristle brush, and rinse with acetone until there are no visible particles. Make a final acetone rinse.

c) For probe liner, repeat rinse, brush, rinse sequence at least three times for glass liners, and six times for metal liners.

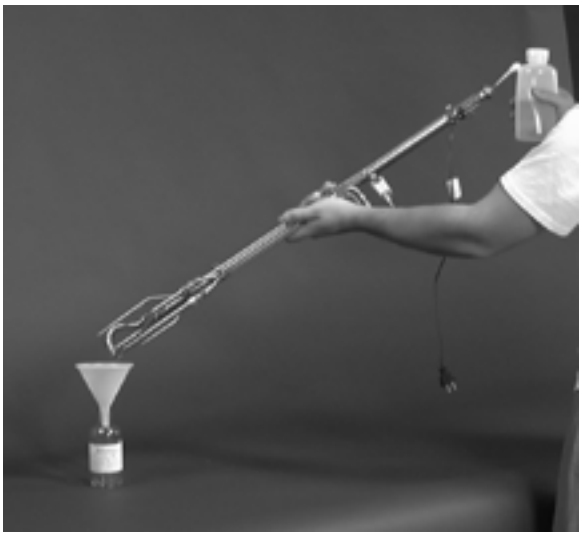


Figure 2-30 Sample Recovery from Probe Liner

Tips from an Old Stack Tester

Instead of trying to catch the probe rinse with a glass funnel and sample container (likely step for sample loss), clamp an Erlenmeyer flask outfitted with female ball joint on the probe liner ball joint and conduct the probe rinse procedure. If the probe is short, one person can perform the brushing and rinsing.

Figure 2-31 Rinsing Probe Nozzle

Figure 2-32 Brushing Probe Nozzle

Figure 2-33 Front Half Acetone Rinse Samples

d) Make a final rinse of the probe brush with acetone.
e) For Probe Nozzle, use the nylon nozzle brush and follow the same sequence of rinse, brush, rinse as for the probe linger.
f) After completing the rinse, tighten the lid on the sample container. Mark the height of the fluid level. Label the container.

5. Container No. 3 – Silica Gel

   a) Determine whether silica gel has been completely spent, and note on data sheet its condition and color.
   b) Either reuse in the next run, using the final weight as the initial weight for the new sampling run, or discard and reload impinger.

6. Impinger Water

   a) Note on the data sheet any color or film in the liquid catch.
   b) Discard the liquid, unless analysis of the impinger catch is required. Store as is appropriate.

7. Whenever possible, ship sample containers in an upright position.

At the conclusion of each sampling run, it is prudent to calculate the stack gas moisture (for the next sampling run) as well as the average isokinetic rate. To calculate the stack gas moisture content (B_{ws}), the following equations are used to compute the sample gas volume ($V_{m(std)}$) and gas moisture volume ($V_{wc(std)}$):

$$V_{m(std)} = K_3 Y \frac{V_m\left(P_{bar} + \frac{\Delta H}{13.6}\right)}{T_m}$$

where ΔH = Average orifice tube pressure during sampling, mm H_2O (in. H_2O)
V_m = Dry gas volume measured by dry gas meter, dcm (dcf)
T_m = Absolute temperature at dry gas meter, °K (°R)
Y = Dry gas mater calibration factor
K_3 = 0.3858 °dK/mm Hg (metric units)
= 17.64 °R/in. Hg (English units)

$$V_{wc(std)} = K_2(W_f - W_i)$$

where W_f = Final weight of water collected, g
W_i = Initial weight of water collected, g
K_2 = 0.001335 m^3/g (metric units)
= 0.04715 ft^3/g (English units); and

$$B_{ws} = \frac{V_{wc(std)}}{V_{m(std)} + V_{wc(std)}}$$

where B_{ws} = Proportion of water vapor, by volume, in the gas stream.

Next, the average stack gas velocity is calculated. The equation for average gas velocity in a stack or duct is:

$$V_s = K_p C_p \left(\sqrt{\Delta p}\right)_{avg} \sqrt{\frac{T_{s(avg)}}{P_s M_s}}$$

where V_s = Average stack gas velocity, m/sec (ft/sec)
C_p = Pitot tube coefficient, dimensionless
$(\sqrt{\Delta p})_{avg}$ = Average of the square roots of each stack gas velocity head
T_s = Absolute average stack gas temperature, °K (°R)
P_s = Absolute stack gas pressure, mmHg (in. Hg)
= $P_{bar} + P_g/13.6$

P_{bar} = Barometric pressure at measurement site, mm Hg (in. Hg)

P_g = Stack static pressure, mm H2O (in. H2O)

M_s = Molecular weight of stack on dry basis, g/g-mole (lb/lb-mole)

= $M_d (1-B_{ws}) + 18.0 B_{ws}$

M_d = Molecular weight of stack on dry basis, g/g-mole (lb/lb-mole)

K_p = Constant, 34.97 for metric system (85.49 for English system)

The average percent isokinetic sampling rate is calculated as:

$$\%I = \frac{K_4 T_s V_{m(std)}}{P_s v_s A_n \theta (1 - B_{ws})}$$

where A_n = Cross-sectional area of the nozzle, m^2 (ft^2)

θ = Sampling time, minutes

K4 = 4.320 (metric units)

= 0.09450 (English units)

At the conclusion of each sampling run, it is prudent to calculate the stack gas moisture (for the next sampling run) as well as the average isokinetic rate. To calculate the stack gas moisture content (B_{ws}), the following equations are used to compute the sample gas volume ($V_{m(std)}$) and gas moisture volume ($V_{wc(std)}$):

$$V_{m(std)} = K_3 Y \frac{V_m \left(P_{bar} + \frac{\Delta H}{13.6} \right)}{T_m}$$

where ΔH = Average orifice tube pressure during sampling, mm H_2O (in. H_2O)

V_m = Dry gas volume measured by dry gas meter, dcm (dcf)

T_m = Absolute temperature at dry gas meter, °K (°R)

Y = Dry gas meter calibration factor

K_3 = 0.3858 °K/mm Hg (metric units)

= 17.64 °R/in. Hg (English units)

$$V_{wc(std)} = K_2 \left(W_f - W_i \right)$$

where W_f = Final weight of water collected, g

Wi = Initial weight of water collected, g

K_2 = 0.001335 m^3/g (metric units)

= 0.04715 ft^3/g (English units); and

$$B_{ws} = \frac{V_{wc(std)}}{V_{m(std)} + V_{wc(std)}}$$

where B_{ws} = Proportion of water vapor, by volume, in the gas stream.

Next, the average stack gas velocity is calculated. The equation for average gas velocity in a stack or duct is:

$$v_s = K_p C_p \left(\sqrt{\Delta p}\right)_{avg} \sqrt{\frac{T_{s(avg)}}{P_s M_s}}$$

where v_s = Average stack gas velocity, m/sec (ft/sec)

C_p = Pitot tube coefficient, dimensionless

$(\sqrt{\Delta p})_{avg}$ = Average of the square roots of each stack gas velocity head

T_s = Absolute average stack gas temperature, °K (°R)

P_s = Absolute stack gas pressure, mm Hg (in. Hg)

$= P_{bar} + P_g/13.6$

P_{bar} = Barometric Pressure at measurement site, mm Hg (in. Hg)

P_g = Stack static pressure, mm H_2O (in. H_2O)

M_s = Molecular weight of stack on wet basis, g/g-mole (lb/lb-mole)

$= M_d (-B_{ws}) + 18.0\ B_{ws}$

M_d = Molecular weight of stack on dry basis, g/g-mole (lb/lb-mole)

K_p = Constant, 34.97 for metric system (85.49 for English system)

The average percent isokinetic sampling rate is calculated as:

$$\%I = \frac{K_4 T_s V_{m(std)}}{P_s v_s A_n \theta (1 - B_{ws})}$$

where A_n = Cross-sectional area of the nozzle, m^2 (ft^2)

θ = Sampling time, minutes

K_4 = 4.320 (metric units)

= 0.09450 (English units)

Tips From an Old Stack Tester

During port changes, many stack testers scan or quickly average values for √Δp, ΔH, stack gas temperature and DGM temperature to calculate %I before the sampling run is finished (this all assumes that B_{ws} will not change substantially). Some sophisticated calculator programs and most laptop computer programs monitor %I for each point and

Recommended Reading List for Isokinetic Sampling

Code of Federal Regulations. Title 40. Part 60, Appendix A. Office of the Federal Register. National Archives and Records.
Compliance Test Coordination and Evaluation. Workshop Manual. U.S. Environmental Protection Agency. APTI 01-94a. 1994.
Jahnke, J. A., et al. *Source Sampling for Particulate Pollutants.* Student Manual, APTI Course 450. Edition 3.0. Raleigh, NC: North Carolina State University, 1995.
Manual for Coordination of VOC Emissions Testing Using EPA Methods 18, 21, 25, and 25A. U.S. Environmental Protection Agency. EPA 340/1-91-008. September 1991.
Quality Assurance Handbook for Air Pollution Measurement Systems. Vol. 3. Stationary Source Specific Methods, Section 3.4. U.S. Environmental Protection Agency. EPA-600/4-77-027b. 1988.
Rom, J. J. Maintenance, Calibration, and Operation of Isokinetic Source Sampling Equipment. Publication No. APTD-0576. Office of Air Programs. U.S. Environmental Protection Agency. Research Triangle Park, NC 1972

Chapter

3

Calibration & Maintenance

Setting up and adhering to a routine maintenance program will help to ensure trouble-free operation of the isokinetic sampling system. In addition, a carefully documented maintenance and calibration system will help to assure that accurate results are obtained during stack testing activities. The following text describes maintenance and troubleshooting procedures for the various subsystems of the isokinetic sampling system.

Calibration Procedures

Test results from a stack emission test are meaningless without calibration of the equipment components. The creation and maintenance of a regularly scheduled calibration and record keeping program are critical to conducting any stack testing program. Without calibration, sampling cannot be verified as having been conducted isokinetically.

The results of a particulate sampling test cannot be checked for accuracy because no independent technique or test atmosphere exists to provide a standard or known particle concentration. Collaborative testing conducted by the USEPA has determined that the interlaboratory standard deviation is ± 12.1%. Only through careful calibration, maintenance, and record keeping can the stack tester ensure that the data collected during the stack test program are representative of particle concentrations and mass emission rate.

Components of the particulate sampling system which require calibration are:

1. Dry Gas Meter and Orifice Tube
2. Thermocouples (stack, probe, filter box, impinger exit, and dry gas meter) and Digital Temperature Indicator
3. Pitot Tube
4. Sampling Nozzles
5. Probe and Filter Box Heater System.

Table 3-1 presents a summary of the calibrations required, equipment used for calibration, acceptance limits, calibration frequency and actions required if calibration fails to meet acceptance limits.

Component	Calibrated Against	Acceptance Limits	Frequency	Action If Unacceptable
Dry Gas Meter Initial 5-point	1. Wet Test Meter 2. Secondary Reference DGM	$Y_i = Y \pm 0.05Y$	Semiannually	Recalibrate, repair or replace
Post-test 3-point	1. Wet Test Meter 2. Reference DGM 3. Critical Orifices	$Y = Y \pm 0.05Y_{avg}$	After each field test	Recalibrate at 5-points
Orifice Tube	Measured during DGM calibration	$\Delta H_@ = 46.7 \pm 6.4$ mm H_2O (1.84 ± 0.25 in. H_2O)	With DGM	Repair or replace
Thermocouples and Digital Indicator	Certified Hg-in-glass thermometer in ice slush and boiling water	Stack: ±1.5% °K DGM: ±3°C Probe: ±3°C Filter: ±3°C Exit: ±1°C	After each field test	Recalibrate, repair or replace
Pitot Tube	1. Standard pitot tube in wind tunnel and calculate C_p	If part of Probe Assembly, calibrate with assembly. $\sigma \leq 0.001$ for side A and side B	Quarterly, or after each field test	Recalibrate, repair or replace
	2. Measure with angle indicator to demonstrate meeting geometry specifications and assign $C_p = 0.84$	$\alpha_1 \pm 10°$ $\alpha_2 \pm 10°$ $\beta_1 \pm 5°$ $\beta_2 \pm 5°$ $Z = \leq 0.125$” $W = \leq 0.031$” $P_A - P_B \leq 0.063$” $0.188” \leq D_T \leq 0.375”$	Quarterly, or after each field test	Recalibrate, repair or replace
Sampling Nozzles	Micrometer with at least 0.025-mm (0.001-inch) scale	Average of three inner diameter measurements; $\Delta D \pm$ 0.1-mm (0.004-inch)	Before each field use	Recalibrate, reshape, or resharpen when dented or corroded
Probe and Filter Box Heater System	Gas thermocouple	Capable of maintaining 120°C ± 14°C at 20-lpm flow rate	Initially	Repair or replace, and verify calibration

Table 3 - 1 Sampling System Equipment Calibration and Frequency

Dry Gas Meter and Orifice Tube

The dry gas meter and Orifice Tube are calibrated simultaneously. In USEPA Method 5, Section 5.3 contains the calibration procedure. An initial or full calibration is conducted at five (5) selected flow rate (ΔH) settings, and should occur once every 6 months or if the results of a post-test 3-point calibration show that the dry gas meter calibration factor (Y) has changed by more than 5% from the pre-test calibration value. Quarterly or post-test calibrations use an abbreviated calibration procedure (described in Section 5.3.2 of Method 5) with three calibration runs at a single intermediate ΔH setting.

In calibrating the Source Sampler Console, the operator is determining the dry gas meter calibration factor (Y) which is the ratio of measurement of the wet test meter's volume to the dry gas meter volume. The Orifice Tube calibration factor $\Delta H_@$ is the pressure drop across the orifice for a sampling flow rate of 21.2 lpm (0.75 cfm). It is related to the true Orifice Tube calibration factor by the equation $\Delta H_@ = 0.9244/K_m^2$, where K_m is the orifice calibration factor. The sampling rate of 21.2 lpm (0.75 cfm) is the standard sampling rate for solving the isokinetic equation and setting up the nomograph (sets of equations) for testing.

Both the initial and intermediate calibration procedures are described here. Prior to conducting a calibration run, the portion of the sampling train from the pump to the Orifice Tube in the Source Sampler Console should be leak-checked.

Metering System Leak Check Procedure (Vacuum Side)

Figure 3-1 shows a plumbing diagram of the MC-500 Series Source Sampler Console.

1. Connect the Vacuum Pump to the Source Sampler Console.
2. Close the Coarse Valve on the Source Sampler Console.
3. Insert a plugged male quick-connect into the SAMPLE quick-connect inlet.
4. Turn on the pump.
5. Open the Coarse Valve and fully close (FINE INCREASE) the Fine Increase Valve.
6. The Vacuum Gauge should read 92-kPa (27 in. Hg) for a barometric pressure of 100 kPa (30 in. Hg)
7. After the ΔH manometer has returned to the zero mark, using the dry gas meter gauge and a wristwatch or timer, note whether the leak rate exceeds 0.28 lpm (0.01 cfm). If the leak rate is greater, turn off the pump and check connections of the tubing and piping on the Pump, Vacuum Gauge, and metering valves. Check the tubing also for leaks.
8. Close the Coarse Valve and observe the Vacuum Gauge. If there is no loss of vacuum, the vacuum side of the Source Sampler Console is leak free.
9. The Pressure Side Leak Check will need to be performed next by following the directions in the next section. The Rockwell dry gas meter in the MC-522, English version of the MC-572, will run backwards if there is a leak on the Pressure Side when completing the Vacuum Side Leak Check. The Kimmon dry gas meter in the MC-572 will not run backward thus requiring a Pressure Side Leak Check.

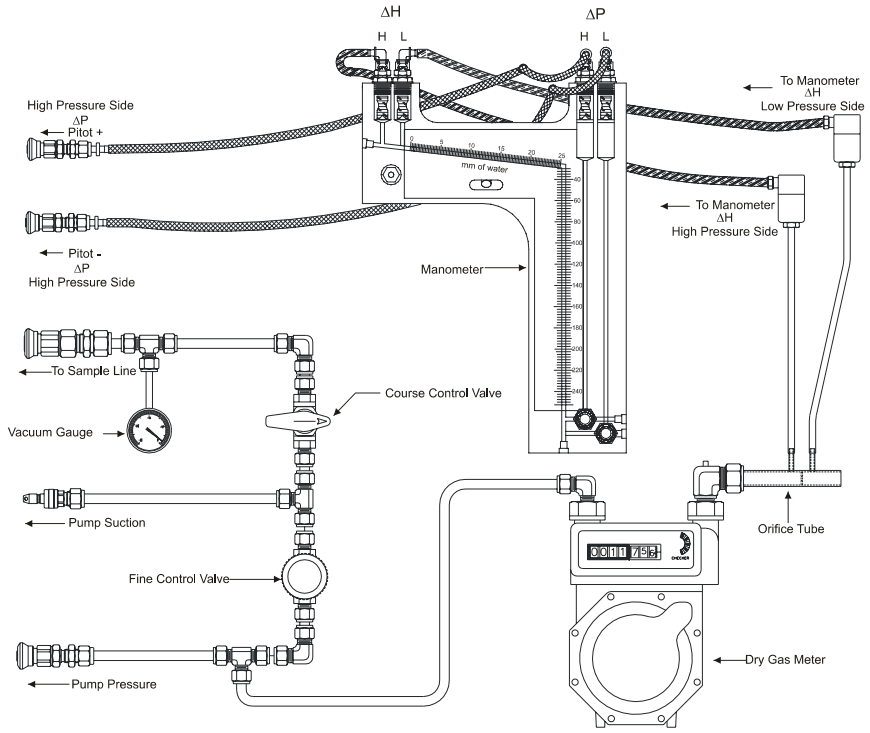


Figure 3 - 1 Source Sampler Console Plumbing Diagram for Leak Check

Metering System Leak Check Procedure (Pressure Side)

There are several techniques for performing a "back-half" or pump discharge Source Sampler Console leak check. The following procedure is based on USEPA recommendation contained in Section 5.6 of Method 5.

1. Connect the Vacuum Pump to the Source Sampler Console.
2. Plug the outlet of the Orifice Meter with a rubber stopper.
3. Insert both pitot (Δp) manometer plastic connectors onto the right side of the dual-column manometer.
4. Insert both orifice (ΔH) manometer plastic connectors onto the left side of the dual-column manometer.
5. To pressurize the system, remove one the of the ΔH plastic connectors and then blow lightly into the tubing until the ΔH reads 177.8 to 254-mm (7 to 10-inches) H_2O
6. Pinch off the tubing securely, and insert the ΔH plastic connector back into the manometer. Allow the manometer oil time to stabilize.
7. Observe for one minute. Any loss of pressure during this minute indicates leakage, which must be corrected. Check all connections and tubing for leaks.

Initial or Semiannual Calibration of Dry Gas Meter and Orifice Tube

The Source Sampler Console (dry gas meter and Orifice Tube) is calibrated by connecting the Source Sampler Console to a wet test meter or secondary reference dry test meter, according to the set-ups shown in Figures 3-2 and 3-3. A series of five (5) calibration runs are conducted at differing flow rates (ΔH settings) which bracket the range of expected sampling rates during particulate sampling tests.

If a wet test meter is used as the calibration standard, it should have a meter correction factor of 1.000. Alternatively, a properly calibrated secondary reference dry gas meter may be used to calibrate the Source Sampler Console's dry gas meter. Use the following procedure:

1. Before starting the calibration, fill out a meter calibration data sheet (can be a computer spreadsheet) as shown in Appendix C. Record barometric pressure at the start of calibration, the Source Sampler Console and wet test meter identification numbers, date and time of calibration, and confirmation of acceptable leak checks on the Source Sampler Console.
2. Connect the outlet of the wet test meter to the inlet (SAMPLE) of the Console Meter.
3. Turn on the Vacuum Pump and adjust the Coarse and Fine control valves on the Source Sampler Console until a ΔH of 12.7-mm (0.5-in.) H_2O is obtained at a vacuum of between 8 and 15 kPa (2-4 in. Hg) on the Vacuum Gauge. Allow both meters to run in this manner for at least 15 minutes to let the meter stabilize and the wet test meter to wet the interior surfaces.
4. Turn off the Vacuum Pump.
5. Record initial settings of ΔH, dry gas meter volume reading, wet test meter volume reading, dry gas meter temperature, and wet test meter temperature.
6. Start the Vacuum Pump and quickly adjust the ΔH to the desired setting. Start the Elapsed Timer on the Source Sampler Console at the same time that the pump is started.
7. Let the Vacuum Pump run until a dry gas volume of approximately 140 liters, (5 cubic feet) is indicated by the dry gas meter. Allow the calibration run to continue until the next minute elapses, then stop the Vacuum Pump and Elapsed Timer.
8. Record the final dry gas meter volume reading, wet test meter volume reading, dry gas meter temperature, and wet test meter temperature. Calculate the dry gas meter and wet test meter volumes by subtracting initial readings from final readings. Calculate the average dry gas meters and wet test meter temperatures.
9. Repeat the calibration run at each successive setting of ΔH. Suggested ΔH values are 13, 26, 39, 52, 65 and 78 mm H_2O (0.5, 1.0, 1.5, 2.5, 3.5 and 4.5 in. H_2O), recording the same data as before.
10. At the conclusion of the five calibration runs, calculate the average Y (ratio of accuracy of the wet test meter to the dry gas meter) and $\Delta H_@$ values. The tolerance for individual Y values is ± 0.02 from the average Y. The tolerance for individual $\Delta H_@$ values is ± 6.4-mm (0.25-in) H_2O from the average $\Delta H_@$. If a value in this range is not obtained, the orifice opening should be adjusted or the Orifice Tube replaced. If the Y and $\Delta H_@$ are acceptable, record the values on a label on the front face of the Console Meter.

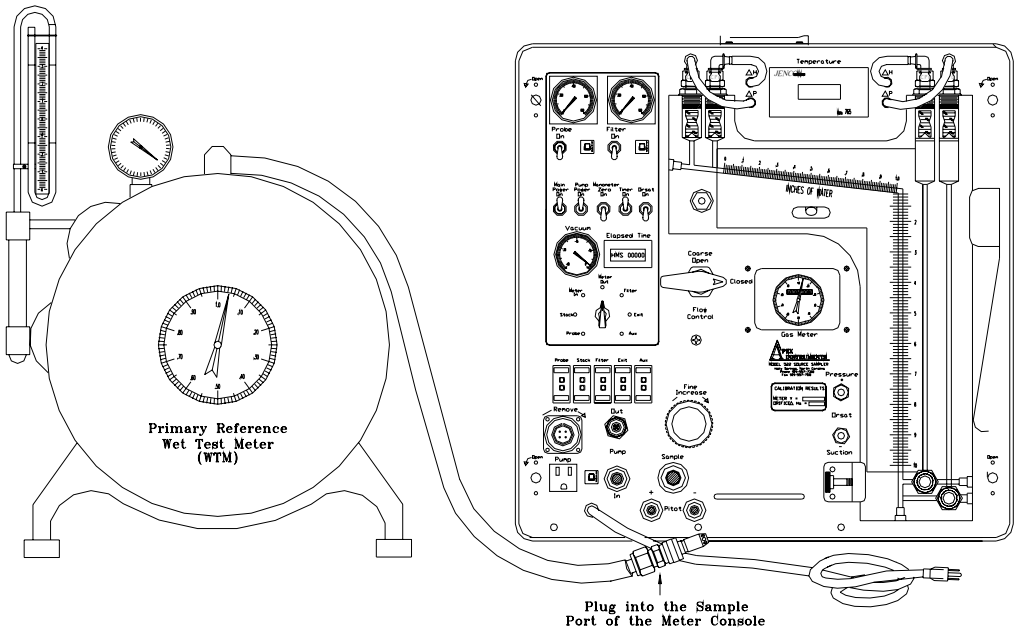


Figure 3 - 2 Set-up for Calibrating the Source Sampler Console Against Wet Test Meter

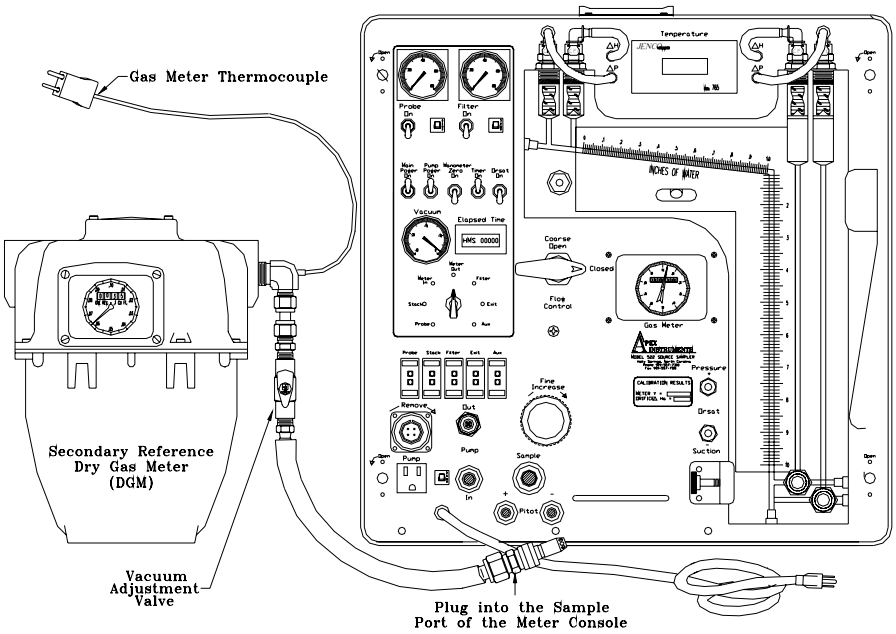


Figure 3- 3 Illustration of Console Meter Calibration with Secondary Reference Dry Gas Meter

Post-Test Calibration of the Source Sampler Console

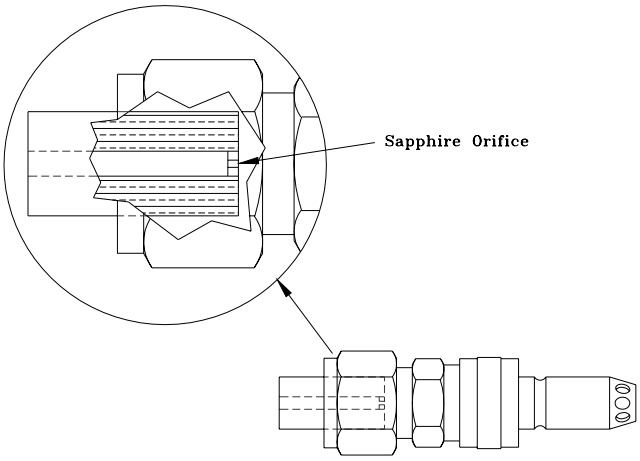


Figure 3 - 4 Critical Orifice Used for Calibration

A post-test, or 3-point, calibration of the Source Sampler Console should be conducted after each trip to and from the field or test series to ensure that the dry gas meter correction factor (Y) has not changed by more than 5%. With a critical orifice set as shown in Figure 3-4, this can be done in the field before departing the test site. Follow the same directions below, except substitute the critical orifice for the wet test meter and ensure that the vacuum is 25-50 mm Hg (1-2 inches Hg) above the critical vacuum. A post-test calibration check is conducted at the average ΔH and highest system vacuum observed during the test series. Use the following procedure:

1. Before starting the calibration, fill out a meter calibration data sheet (can be a computer spreadsheet) as shown in Appendix C. Record barometric pressure at the start of calibration, the Source Sampler Console and wet test meter (or secondary DGM or critical orifice) identification numbers, date and time of calibration, and confirmation of acceptable leak checks on the Source Sampler Console.

2. Connect the outlet of the wet test meter to the inlet (SAMPLE) of the Source Sampler Console, as depicted in Figure 4-2. Insert a valve between the wet test meter and the inlet of the Source Sampler Console to adjust the vacuum to desired level. If using a Critical Orifice, simply insert the male quick connect end of the critical orifice into the inlet (SAMPLE) of the Source Sampler Console.

3. Turn on the Vacuum Pump and adjust the Coarse and Fine control valves on the Source Sampler Console until a ΔH equivalent to the average ΔH observed during the test series is attained. Set the calibration system vacuum to the highest vacuum observed during the test series. Allow both meters to run in this manner for at least 15 minutes to let the meter stabilize and the wet test meter to wet the interior surfaces. If using a Critical Orifice, select an orifice with ΔH properties similar to the average ΔH observed during the test series. Also, the vacuum will be independent of the vacuum observed during the test series. This is due to the physics of the critical orifice requiring the vacuum to be greater than the theoretical critical vacuum. Theoretical critical vacuum can be estimated at one-half (1/2) of barometric pressure. It is recommended to sample at max vacuum with the Coarse Valve fully opened and the Fine Valve fully closed.

4. Turn off the Vacuum Pump.
5. Record initial settings of ΔH, dry gas meter volume reading, wet test meter volume reading, dry gas meter temperature, and wet test meter temperature.
6. Start the Vacuum Pump and quickly adjust the ΔH to the desired setting. Start the Elapsed Timer on the Source Sampler Console at the same time that the pump is started.
7. Let the Vacuum Pump run until a dry gas volume of approximately 140 liters (5 cubic feet) is indicated by the dry gas meter. Allow the calibration run to continue until the next minute elapses, then stop the Vacuum Pump and Elapsed Timer.
8. Record the final dry gas meter volume reading, wet test meter volume reading, dry gas meter temperature, and wet test meter temperature. Calculate the dry gas meter and wet test meter volumes by subtracting initial readings from final readings. Calculate the average dry gas meter and wet test meter temperatures.
9. Calculate the meter correction factor Y. Repeat the calibration two (2) more times at the same ΔH and system vacuum and calculate the average Y for the three runs.
10. Calculate the percent change in the meter correction factor Y.
11. If the dry gas meter Y values obtained before and after the test series differ by more than 5%, the test series shall be either voided, or calculations for the test series shall be performed using the lower Y value (gives lower sample volume, therefore higher concentration values).

Calibration of Thermocouples

Apex Instruments suggests the following procedures for calibrating thermocouples and temperature display readouts. Thermocouples should be checked for calibration at three temperatures, for example, ice-point and boiling point of water and ambient temperature. Thermocouples such as the stack gas thermocouples, which are used at higher temperatures than boiling water can be checked for calibration using a hot oil bath. Another more modern technique is to use a Thermocouple Simulator Source (M5C-22), as shown in Figure 3-5. The M5C-22 can calibrate without external compensation or ice baths, with a temperature range from 0° to 2,100°F in divisions of 100°F for 22 precise test points.

A temperature sensor calibration form is provided in Appendix C. Acceptable reference materials are:

- ASTM mercury-in-glass reference thermometers,
- NIST-calibrated reference thermocouples/potentiometers,
- Thermometric fixed points, e.g., ice bath and boiling water, or
- NIST-traceable electronic thermocouple simulators.

Calibration of Thermocouples

1. Prepare an ice-water bath in an insulated container (such as the Cold Box).
   a) Insert the thermocouple and a mercury reference thermometer into the bath.
   b) Allow the readings of both to stabilize, and record the temperatures on a thermocouple calibration data sheet, as shown in Appendix C.
   c) Remove the thermocouple and allow it to stabilize at room temperature.
   d) Insert again the thermocouple into the bath, and record another reading.
   e) Repeat Steps c and d.
   f) Calculate the average of the thermocouple readings and the average of the reference thermometer readings. The averages should differ by less than 1.5% of the absolute temperature (°K) for the stack thermocouple.
2. Place a beaker of distilled water on a hot plate, add a few boiling chips and heat to boiling.
   a) Repeat Steps a through f as above.
3. Set both the thermocouple to be checked and a mercury reference thermometer side-by-side at ambient temperature.
   a) Repeat Steps a through f as above.
4. Place a container of oil on a hot plate and heat to a temperature below the boiling point. DO NOT BOIL.
   a) Repeat Steps a through f as above.

Additional calibration procedures are performed on the temperature display. To check the linearity of the temperature display, a thermocouple simulator (Apex Model M5C-22) is used. Connect the simulator to the temperature display, as illustrated in Figure 3-5, and record on a calibration data sheet the display reading at each temperature setting.

Figure 3 - 5 Thermocouple Simulator for Temperature Display Calibration Check

Calibration of Pressure Sensors

The gauge-oil inclined manometer and a mercury-in-glass manometer are primary measuring devices, and thus do not require calibration. When a differential pressure gauge (magnehelic gauge), U-tube manometer, or electronic manometer is used, they must calibrated against a primary measuring device. To check the calibration of differential pressure sensors other than inclined manometers, use the following procedure:

1. Connect the differential pressure sensor to a gauge-oil inclined manometer as shown in Figure 3-6.
2. Vent the vacuum side to atmosphere, and place a pressure on each system.
3. Compare Δp readings of both devices at three or more levels that span the range and record on a calibration data sheet.
4. Repeat Steps 1 through 3 for the vacuum side; vent the pressure side and for the vacuum side place a vacuum on the system.
5. The readings at the three levels must agree within $\pm$ 5% of the reference sensor.

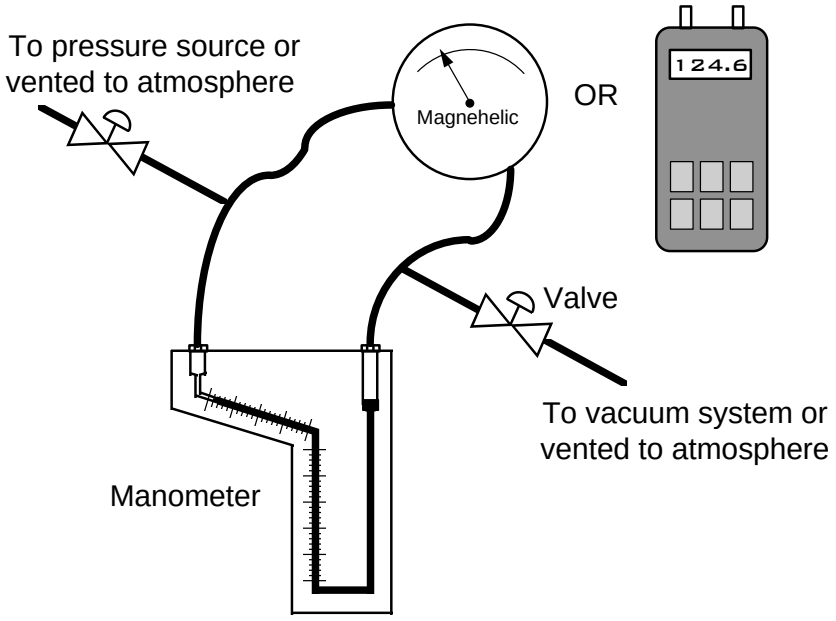
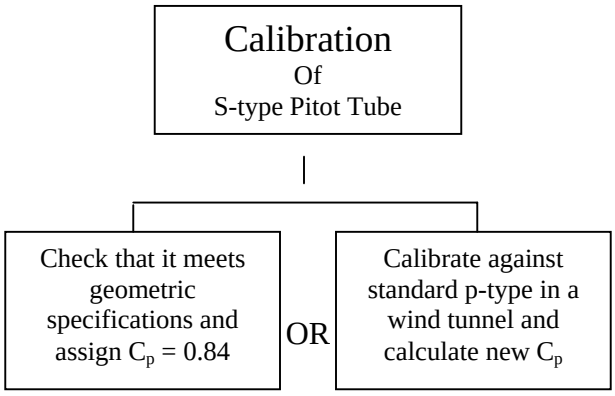


Figure 3 - 6 Set-up for Differential Pressure Sensor Calibration Check

Calibration of Pitot Tube

The construction details of the S-type, or Stausscheibe, pitot tube should be carefully checked when received and prior to calibration. There are two options for calibrating a type-S pitot tube:


Calibration
Of
S-type Pitot Tube
Check that it meets geometric specifications and assign C_p = 0.84
OR
Calibrate against standard p-type in a wind tunnel and calculate new C_p

Apex Instruments provides both geometric and wind tunnel calibrations of type-S pitot tube assemblies at extra charge. The procedures for conducting a wind tunnel calibration are described in detail in US EPA Method 2. When using this procedure, a pitot tube coefficient C_p will typically range from 0.77 to 0.82. Subsequent measurement of stack gas velocity will be more accurate and from 2% to 8% lower. Consequently, stack gas volumetric flow rate and emission rate will be lower. The cost of purchasing or building a wind tunnel is too high for many stack testers, and few have access to a wind tunnel facility. USEPA allows the assignment of a C_p = 0.84 if the pitot tube meets geometric specifications because the error is in the regulatory agency's favor (biases velocity and flow rate high).

The procedure shown on next page describes how to conduct the geometric specifications calibration check.

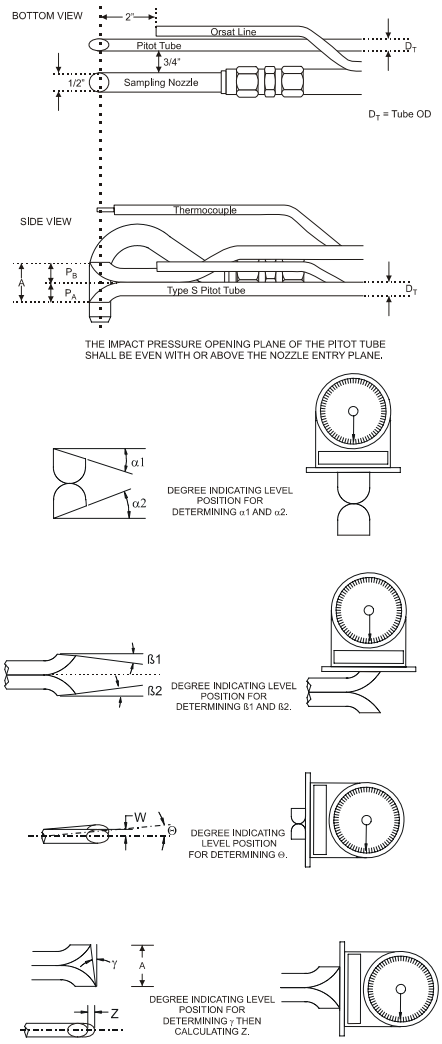


Figure 3 - 7 Calibration of the Probe Pitots

1.	Before starting the calibration check, fill out a pitot tube calibration data sheet as shown in Appendix C (or a computer spreadsheet).
2.	Clamp the pitot tube so that it is level, verify and record.
3.	Verify that the pitot openings are not damaged or obstructed and record.
4.	Using an angle indicator, measure the angles (α_1 and α_2) between the pitot tube opening plane and the horizontal plane when viewed from the end, and record.
5.	Measure the angles (β_1 and β_2) between the pitot tube opening plane and the horizontal plane when viewed from the side, and record.
6.	Calculate the difference in length between the two pitot tube legs (Z) by measuring the angle γ and record.
7.	Calculate the distance that the pitot tube legs are rotated (W) by measuring the angle θ and record.
8.	Measure and record the vertical distances (P_A and P_B) between each pitot tube opening plane and the center line of the pitot tube.
9.	Measure and record the tube external diameter (D_T) and calculate the minimum and maximum values of P_A and P_B.

Calibration of Sampling Nozzles

Probe nozzles should be inspected and calibrated in the field immediately before each use to verify that they were not damaged in transport or shipment. The following procedure, illustrated in Figure 3-8, is recommended:

1. Before starting the calibration check, fill out a probe nozzle calibration data sheet as shown in Appendix C (can be a computer spreadsheet).
2. Using venier or dial calipers with at least 0.025 mm (0.001 inch) tolerance, measure the inside diameter of the nozzle by taking three readings approximately 45-60° apart from one another, and record.
3. Calculate the average of the three readings.
4. If readings do not fall within 0.1-mm (0.004-inches) of one another, nozzle must be reshaped, resharpened and recalibrated.
5. With a permanent marking tool, identify each nozzle with a unique number.

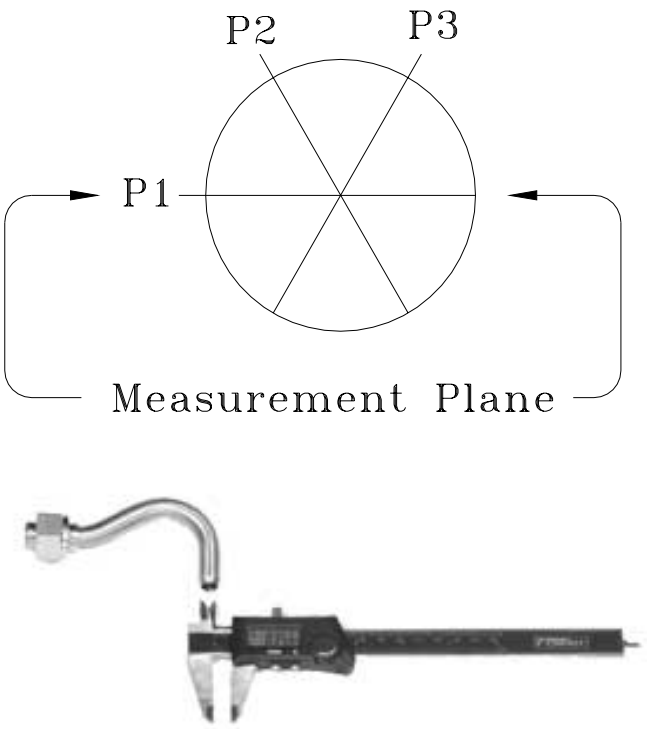


Figure 3 - 8 Calibration of Sampling Nozzle

Initial Calibration of Probe Heater

Apex Instruments calibrates the probe heater assembly before shipping according to procedures outlined in US EPA APTD-0576. Probes are constructed according to specifications given in US EPA APTD-0581, which is the original 1971 document entitled "*Construction Details of Isokinetic Source-Sampling Equipment*," by Robert M. Martin. (Available from National Technical Information Service (NTIS) as document PB-203 060.) The procedure in APTD-0576 involves passing heated gas at several known temperatures through a probe assembly, and monitoring and verifying that the probe assembly is capable of maintaining 120°C ± 14°C, as shown in Figure 3-9.

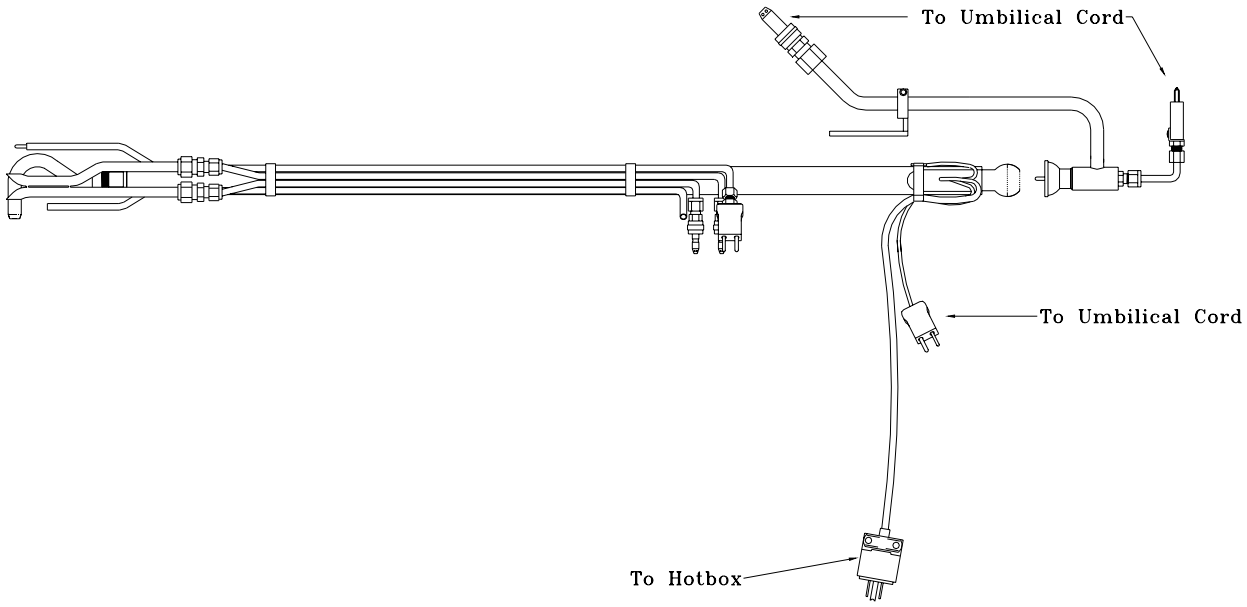


Figure 3 – 9 Set-up for Probe Heater Calibration

Maintenance

External Pump Assembly

The Gast rotary vane pump (E-0523) is a precision product, with only 0.051 mm (0.002") clearance at the top and 0.0635-0.0889 mm (0.0025"-0.0035") total at the ends of the rotor. The vanes take up their own wear and should last 5,000 to 15,000 hours operation depending upon application. Remember: The pump is designed for pumping clean, dry air. It is built of cast iron and steel. Protect it against entrance of dirt, excessive moisture and chemical contamination, lubricate it and you will receive years of trouble-free service.

Maintenance and troubleshooting procedures for the rotary vane pump is as follows:

Inspection Regular inspection and flushing may prevent excessive repairs. Dirty or clogged filter felts can be responsible for failure of pump to build up vacuum, and eventually causes overheating of pump. WARNING: THE MOTOR IS THERMALLY PROTECTED AND WILL AUTOMATICALLY RESTART WHEN PROTECTOR RESETS. ALWAYS DISCONNECT POWER SOURCE BEFORE SERVICING. PERSONAL INJURY AND/OR PROPERTY DAMAGE MAY RESULT. Remove the felts and wash in Flushing Solvent (see Flushing). If there is overheating or excessive noise, stop pump immediately for repairs. It may be quickest and least expensive to send the pump unit for repair.

Starting If motor fails to start or slows down when under load, turn off and unplug. Verify that the voltage agrees with the motor post terminals and motor data nameplate. Also examine plug and switch. If pump unit is extremely cold, bring to room temperature before starting. If trouble appears to be in motor, it may be cheaper to return unit to pump manufacturer than to call an electrician, especially within the guarantee period. NOTE: ALL DUAL VOLTAGE MOTORS ARE SHIPPED FROM FACTORY SET FOR HIGH VOLTAGE.

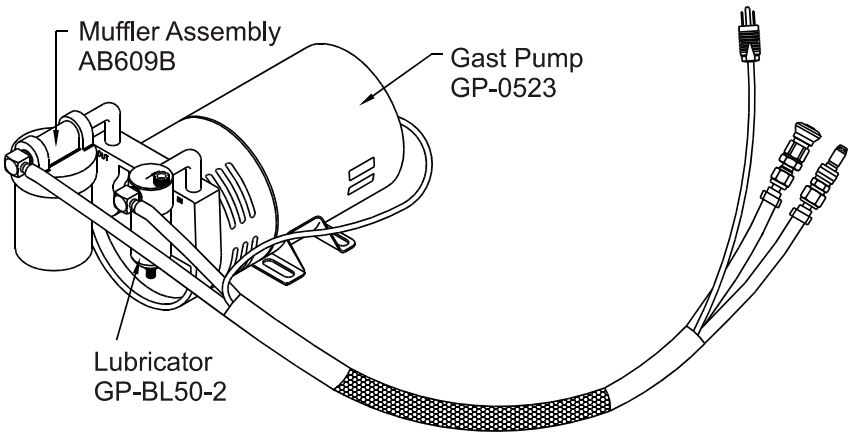


Figure 3-10 Diagram of E-0523 Rotary Vacuum Pump

Lubrication Use of correct oil and proper amount of oil will ensure years of operation. A film of oil provides the seal for the vanes to ride on and fill any tolerance clearance. Use Gast AD220 Oil (order Part #AD220), or a high detergent SAE-10 or SAE-5 automotive engine oil may be used as an equivalent to Gast AD220. In ambient locations with temperatures over 38°C (100°F) SAE-20 oil should be used.

The Lubricators may be filled only under no pressure. For proper lubrication fill oil jar to level indicated on outside of jar. To check lubrication, hold a thumbnail or small mirror near the pump exhaust. A heavy film indicates over-lubrication. Lubrication rate should be adjusted by raising and lowering wick. HAND TIGHTEN ONLY!

To Add Oil:

1. Unscrew reservoir
2. Add oil to reservoir approximately ¾ full. (See **Figure 3-11**)
3. Replace reservoir. Hand tighten only.

To Adjust Oil Flow:

1. Loosen nylon screw as in **Figure 3-11**.
2. Move wick up for more oil or down for less oil as in diagram. (Be careful! Wick is fragile and breakable.)
3. Re-tighten nylon screw.
4. Replace reservoir.

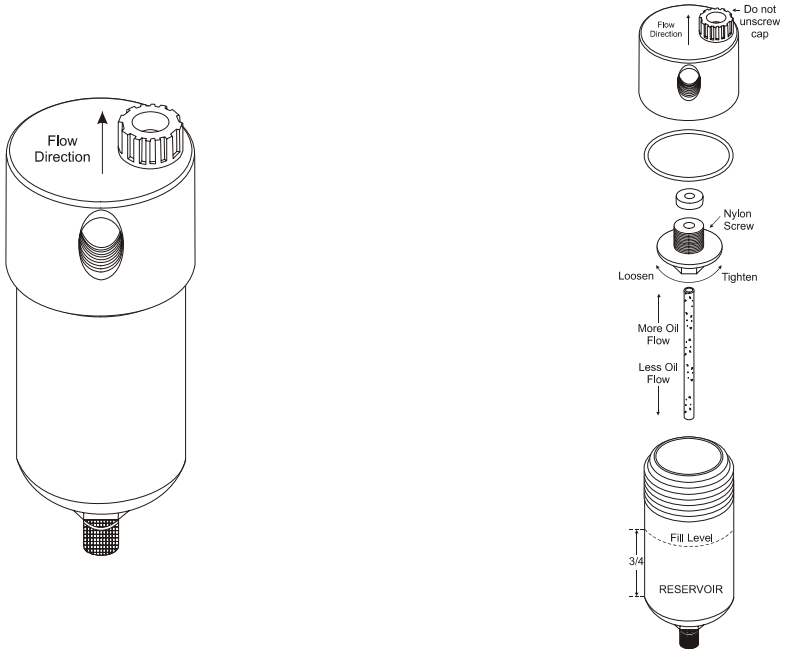


Figure 3-11 GP-BL50-2 Lubricator Assembly

Flushing

Most pump trouble can be corrected by flushing rather than disassembly. A noisy or inefficient pump is frequently nothing more serious than a vane or vanes stuck in rotor slot due to excessive oil or foreign material inside pump.

- Disconnect the power to the pump unit. The inlet and outlet couplers need to be disconnected also. *(Exercise extreme caution, as the pump head and motor may be extremely hot.)*
- Remove the filter insert **(See Figure 3-12)** from the muffler jar. Reinstall the muffler jar and tighten. **HAND TIGHTEN ONLY!**
- Wrap the end of the pressure hose in newspaper or disposable rags. (This will catch the oil mist that is dispersed.)
- Turn on the pump and add several teaspoons of solvent (Gast Flushing Solvent #AH255 or non flammable solvent; WD-40 is commonly used by most stack testers) directly into the vacuum hose. This should be done until the oil coming from the pressure hose looks clean. The pump should be run for another five minutes in order to clear out any remaining oil.

DO NOT USE KEROSENE, GASOLINE OR ANY OTHER FLAMMABLE LIQUID. PERSONAL INJURY AND/OR PROPERTY DAMAGE MAY RESULT. Flush the pump in a well-ventilated area. Eye protection is recommended. Keep face away from exhaust port and do not flush with flammable solvents.

- Clean the lubricator and replace the oil. **(See Figure 3-11)** Use Gast Oil #AD220 or SAE #10 Oil.
- Remove the muffler jar again and clean thoroughly. Clean or replace the filter insert as necessary. **(See Figure 3-12)** Re-install the muffler jar and hand tighten.

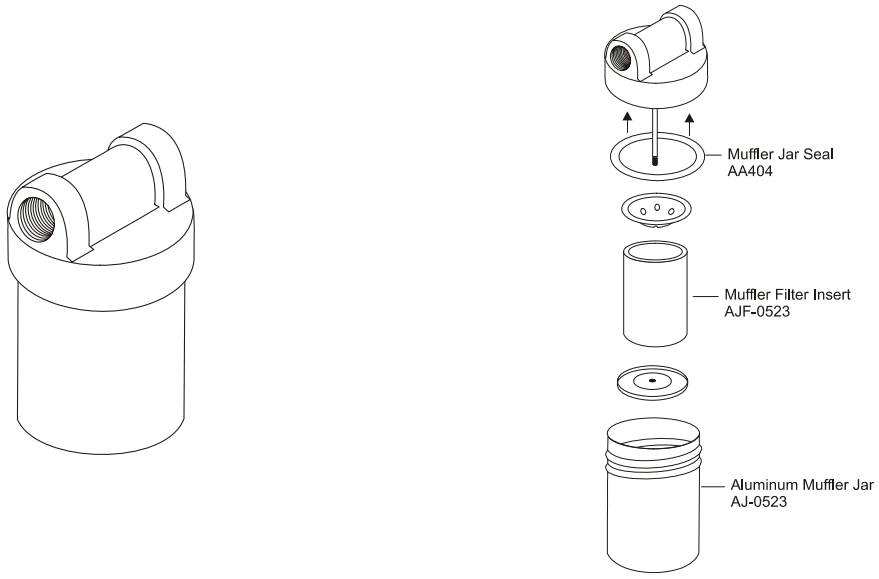


Figure 3-12 AB609B Muffler Assembly

Disassembly If foreign matter has entered pump, try flushing. If this does not eliminate foreign matter, remove ONLY the end plate and the four vanes, as in **Figure 3-13**. (DO NOT at any time remove the rotor or loosen any of the electrical motor "thru-bolts"). Wash vanes, end plate and pump chamber with Flushing Solvent #AH225. Dry and re-lubricate lightly. **(When replacing vanes be sure angled ends are oriented properly. See drawing in Figure 3-13)** If pump fails to produce proper vacuum, the top clearance between the rotor and body may have increased. A metallic clanging could mean that the rotor and the body are touching. Remove end plate, loosen body bolts, and set top clearance at 0.051 mm (0.002"). This can be done by lightly tapping with a miniature hammer on the pump body (either top or bottom, depending on whether clearance is too large or too small). The rotor should be turned while setting clearance so that all points on the circumference of rotor will clear. End clearance, total for both sides of rotor, may vary from 0.0635 mm to 0.0889 mm (0.0025" to 0.0035").

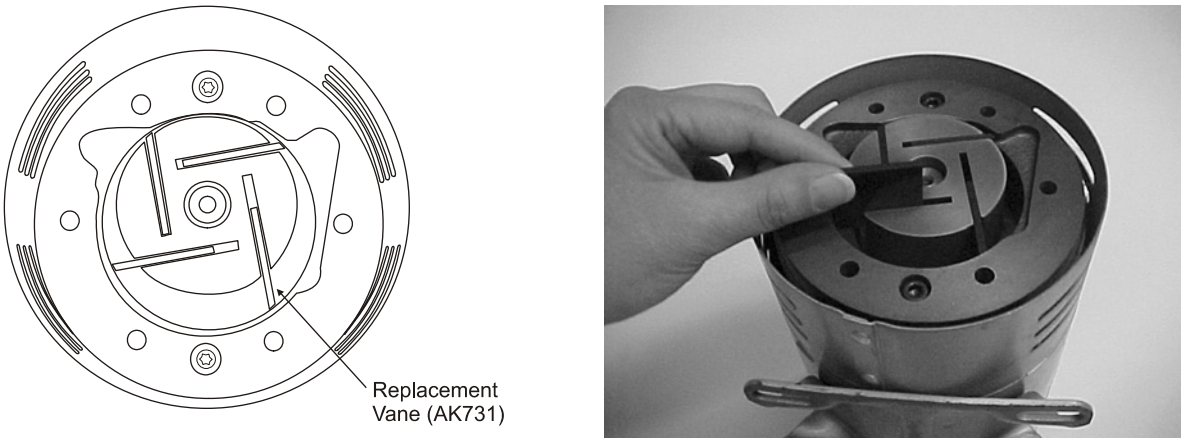


Figure 3-13 Vane Replacement

Source Sampler Console

To inspect the inside components of the Source Sampler Console, make sure the power cord is disconnected. Remove the front panel and tray from the cabinet by turning the four panel latches (in corners of front panel) counterclockwise with a flathead screwdriver until the latch releases. Slide out the panel using the handle at the bottom-center of the faceplate. Once the panel is partially pulled out, reach inside and disconnect the fan wire from the fan assembly. Visually inspect all of the mechanical and electrical components. Clean any accumulated dust off the components.

Dry Gas Meter

The dry gas meter, shown in Figure 3-11, is not field adjustable. The routine maintenance consists of performing the required periodic calibrations and calibration checks. If the dry gas meter fails repeatedly to calibrate against a wet test meter, then return the meter to the factory for repair.

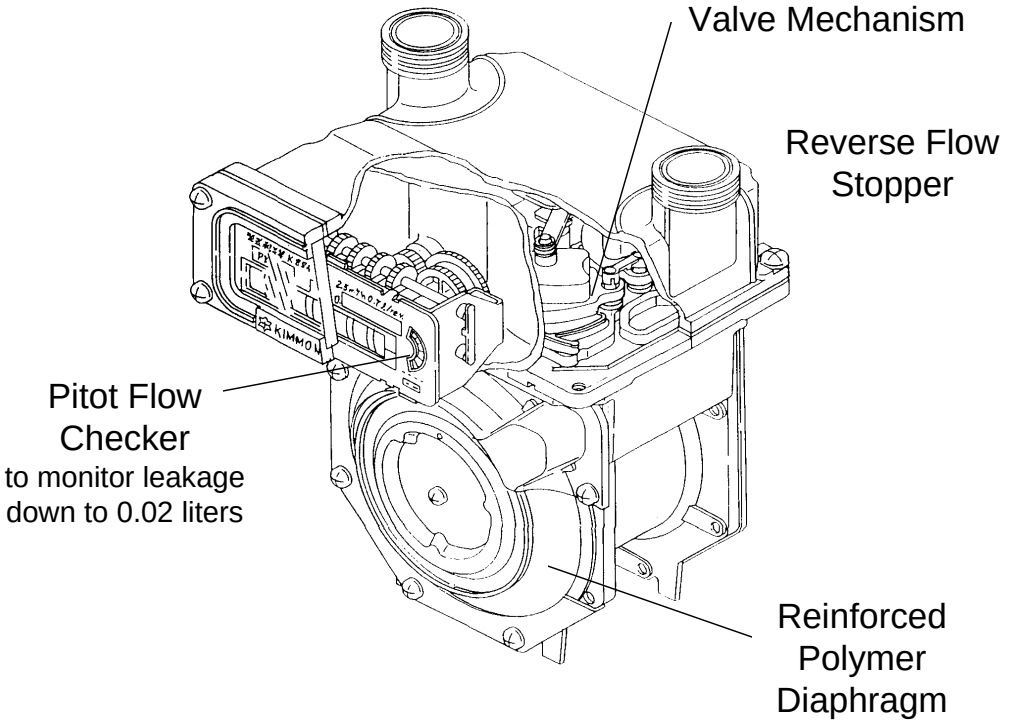


Figure 3-11 Positive Displacement Diaphragm Type Dry Gas Meter

Dual Column Inclined Manometer

Manometer fluids are color-coded for ease of reading in the field: red is used for the pitot tube manometer and orange-yellow for the Orifice Tube manometer.

1) Inspection

- Visually inspect the pitot and orifice manometer lines, both on the front panel and inside back of unit. They should be free of fluid.
- Replace the red manometer fluid, if it is faded.
- Check quick-connect O-rings for cuts or deterioration that may cause leaks. Make sure the plastic quick-connects are engaged and sealed. Check the sight and fluid level. The manometer can be filled with fluid by removing the screw on the left side. When the manometer is zeroed, the fluid level plunger should have about 3 to 6 mm (1/8" to 1/4") travel inward. Replace the fluid-level plunger or O-rings, if necessary.

2) Cleaning

- Wipe the manometer so that it is free from dirt, smudges and grease (use soap and warm water; DO NOT USE hydrocarbon solvents).

3) Leak-Checking

- Check for leaks, especially around the fluid-level plunger and drain screws. Use leak-check procedure given in Section 5.7. Repair leaks by tightening fittings or replacing damaged parts. The manometer screws have sealing washers; DO NOT OVER-TIGHTEN them which can cause stress cracks in the manometer body.

4) Pitot Tube Lines

- Blow through the pitot quick-connects; there should be free movement of air and the manometer should respond by fluid moving away from the side you blow. Check that there are no crimps in the tubing that would affect pressure reading. Pull all ΔP and ΔH lines out as far as possible before installing panel back into cabinet.

5) Orifice Tube Lines

- Turn on the vacuum pump and carefully adjust the Coarse and Fine Increase valves. You should see response on the orifice manometer.
- If it does not respond, check that the Manometer Zero Switch is in the "OFF" position and that the solenoids are working properly. Check that there are no crimps in the tubing.

Manometer Zero Solenoid Valve

The Manometer Zero Switch operates the solenoid valve assembly, which contains two 3-way solenoid valves, and operates only on the Orifice Tube manometer. When the valve switch is turned ON, the two valves close and flow into the manometer is blocked and vented to atmosphere, allowing the pressure to equilibrate.

1) Inspection

- To check the Manometer Zero (ΔH) solenoid valve, turn the switch to "ON." As the solenoids switch from orifice valve to ambient valve, a light "click" should be heard. Allow a few seconds for the ΔH manometer pressure to equalize to atmospheric. Level the manometer by adjusting the leveling screw located in the lower left of the manometer body while viewing the built-in level bubble.
- Zero both manometers by turning the manometer zero displacer knobs. When the manometer is zeroed, the fluid level plunger should have about 3 to 6 mm (1/8" to 1/4") travel inward. If fluid needs to be added, remove the manometer fill screw on the left side toward the top of the manometer. Fill to appropriate level and re-zero. If the fluid is faded or contaminated, drain from the bottom drain screw and refill. Both oils (red and orange) have a specific gravity of 0.826 to match scale calibration.

2) Troubleshooting

- Valve fails to operate

  Check electrical supply with voltmeter. Voltage should agree with nameplate or label rating at the valve.

  Check coil with ohmmeter for shorted or open coil.

  Verify supply pressure is equal to or less than nameplate rating.
- Valve is sluggish or inoperative (Electrical and Pressure OK)

  Disassemble valve operator (see Disassembly instructions). Clean extraneous matter from inside valve. Plunger must be free to move without binding.
- External leakage at sleeve to body joint

  Check that sleeve is torqued to the body with 30-40 inch-pounds and that O-ring seal inside the body is not damaged.
- Internal leakage at sleeve port, energized or de-energized

  Remove sleeve. Examine surface of rubber seals in bottom and top of plunger. Clean or replace plunger as required.

  Inspect orifices in body and sleeve for nicks. Damage may require installing a new valve if problem not solved by repair kit component.

  Return spring must not be broken.

3) **Disassembly** **WARNING**: *Depressurize system and turn off electrical power to valve before attempting repair. Valve needs to be removed from line for disassembly or repair.*

- To remove the coil

  Unscrew nut on top of sleeve. The enclosure, coil and flux plate or integrated coil may now be removed.
- To disassemble pressure vessel
- Placing pliers on sleeve of valve, remove sleeve from the body of the valve. Pliers should be positioned 90° from centerline of sleeve to avoid sleeve damage.

Temperature Controllers

The temperature controllers for probe and filter box heat, after setting temperature to the desired setpoint, receive a signal from the thermocouple subsystem and maintain these temperatures within a close range of the setpoint. The standard temperature controllers are solid-state analog devices with a dial control, as shown in Figure 3-12

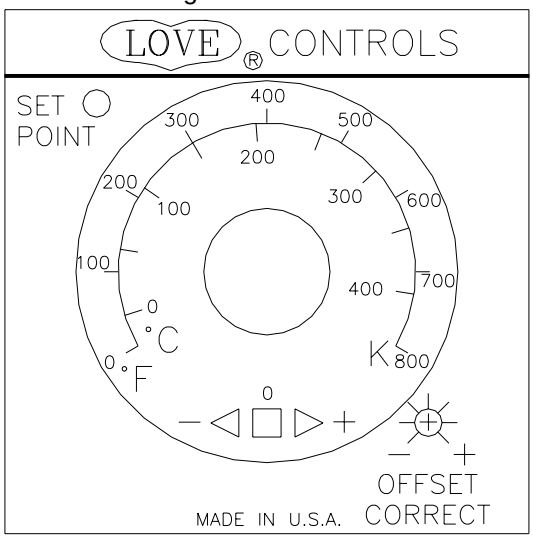


Figure 3-12 Analog Temperature Controller

1) Check Operation

- Adjust the red pointer on dial to desired setpoint. The setpoint LED (upper left corner) should respond as follows: When GREEN, the temperature is within 1.5% of setpoint. When RED, the temperature is below or above setpoint by more than 1.5%.

2) Repair

- Do not attempt to repair unit. *Remove and replace.*

Thermocouple Wiring and Thermocouple Display

The most commonly used thermocouple (TC) in stack testing applications is the Type K. Calibration guidance is given by the USEPA in Emission Measurement Technical Information Center (EMTIC) Guidance Documents GD-024 and GD-028. A Type K TC, even with large wire gauge sizes, will eventually fail if subjected to sustained temperatures ≥ 1,090°C (2,000°F). Even short excursions will shorten the useful life of the TC. Other types of TCs should be considered for sustained temperatures above 1,090°C.

1) TC Wire Not Functioning Properly

⇒ Check to see if TC leads have not detached from screw posts inside TC plugs or receptacles. This causes an open TC circuit when there is NO junction and reads "1" on the temperature display. This condition occurs when there is no device connected to that channel, or when one of the wires in the circuit has broken or become disconnected.

2) Temperature On Display Goes Down When It Should Go Up

⇒ Check continuity of TC by subjecting it to a change in temperature (for example, remove from stack and touch an ice cube). If the temperature goes the wrong way, then polarity of the TC has been reversed. Check each connection for proper polarity: The red wire is negative and yellow wire is positive.

3) TC Reads Lower Value Than Expected

⇒ Under-reading is usually caused by second unintended junction in TC circuit, such as a short in one wire (TC display reads average of two junctions). Most common place for the short is in connectors, with unintended junction reading ambient temperature. Quick check is to disconnect TC at connection farthest away from Source Sampler Console. If display reads "1" for an open circuit, then there is NOT a short in the extension circuit. Check connector on the measuring device.

4) TC Display Susceptible to Static Electricity

⇒ When sampling hot dry gas across probe, ground with a grounding strap to either the Probe Assembly (to the stack) or make sure the Umbilical Cable is always connected.

5) TC Selector Switch

⇒ Clean contacts of accumulated dust periodically with electrical switch spray cleaner. Check switch connections by connecting TC simulator to each receptacle on faceplate and verifying that each channel reads temperature selected by simulator. Note: TCs attached to inlet and outlet of DGM are wired directly to selector switch and should read ambient temperature.

Electrical Power Circuits

Electrical power circuits include the Probe Assembly, Modular Sample Case, Umbilical Cable, and Source Sampler Console connections.

Circular Connector Outlet on Source Sampler Console

Check the Circular connector outlet with a voltmeter or check light by connecting the leads to the different terminals (see Electrical Schematic in Appendix B). When connected across heater lines, voltmeter or check light should respond correspondingly. Solid-state temperature controller circuits should be tested with a resistant load, such as test lamp or heater.

Umbilical Cable

Check the electrical lines of the Umbilical Cable for continuity using an ohmmeter or battery-light system. If there is no continuity in any of the lines, check the circular connector connections. If this not the problem, replace the cord.

Connect the Umbilical Cable to the Source Sampler Console. Check the Umbilical Cable outlet with a voltmeter by connecting the leads to a combination of the four pins: Pin A is

120/240 VAC for auxiliary power, Pin B is common neutral, Pin C is 120/240 VAC for filter heat, and Pin D is 120/240 VAC for probe heat. Voltmeter should respond properly when circular connector is wired correctly and appropriate switches are thrown. Check ground continuity wire with an ohmmeter between Circular connector body and electrical plug ground pin. Ohmmeter should read less than 1 ohm.

Modular Sample Case

Check the probe heater plug with a check light for continuity.

Probe Assembly Tube Heater

Inspect electrical connections to the tube heater and power cord for visible shorts or burned spots in the high-temperature insulation. Connect power cord into suitable power source and monitor temperature. Probe should become warm to touch over its entire length in a few minutes. If probe does not heat, check power source for proper voltage and loose connections in plug. Shorts are indicated by partial heating in rear section of probe. Breaks in heating element and connections can be checked with an ohmmeter or a battery-light system. Replace probe tube heater, if necessary.

Sample (Vacuum) and Pitot (Pressure) Lines on Umbilical Cable

Check the quick-connects and lines on the Umbilical Cable as follows:

Quick-Connects

Wipe vacuum line and pitot line quick-connects clean before attaching to Source Sampler Console. Mating quick-connects should be joined together when not in use to prevent damage and dirt. A drop of penetrating oil on each keeps them in good working condition.

Vacuum Line

Test vacuum line for leaks by plugging inlet with a 12.7 mm (½") quick-connect plug and connect line to Source Sampler Console. Conduct leak-check by pulling vacuum. If leakage is noted, check all connections first and then, if necessary, inspect the tubing (look for crimps). If cause can not be readily identified, slightly pressurize the line and check for leaks using soapy water.

Pitot Lines

Connect one end of pitot line to manometer, and pull vacuum of 250 mm (10 inches), seal tubing at the pump end, and check for leaks by noting loss in manometer level. Do same for other side. If leakage is noted, check connections and tubing same way as for vacuum line.

Appendix A

Equipment Lists for Isokinetic Sampling

Recommended Equipment for Isokinetic Sampling

Apex Instruments, Inc. Intermediate Method 5 Source Sampling System (SY5-CIS) includes the following items:

Qty	Part#	Description
1	MC-572	Model 572 Source Sampler Console with External Pump
1	SB-50	Modular Sample Case, Includes SB-2M, SBR-10 & SB-3
1	PA-6S	6 Foot Stainless Steel Lined Probe Assembly
3	PLN-6G	6 Foot Borosilicate Glass Probe Liner
1	UC-60-15	60 Foot Umbilical Cable with 15 foot Sample Line Cut-Back
1	U-15-SLE	15 Foot Umbilical Sample Line Extension
1	USL-15-SS	15 Foot Flexible Sample Line with Socket Elbow Fittings
1	GA-107-12	Mini Hot Box Sample Line Strain Relief, with ½ inch Clamp
1	GA-109-12	Impinger Inlet Strain Relief, with ½ inch Clamp
1	GA-100	Sample Case/Umbilical Adapter
1	NS-SET	Stainless Steel Nozzle Set
1	GN-DGS	Deluxe M5 Glassware Set with Transport Case
1	GF-3GC	3 inch Glass Fiber Filters-100/box (MFS GC50 82mm)
1	PBX-S	Modular Probe Brush Set, Nylon Brushes with Aluminum Extensions
1	NB-SET	Nozzle Brush Set (sizes 3,5 & 8) in Carrying Tube
1	M5A-1M	Slide Rule Nomograph, Metric Units
2	P1000-9	9 foot Monorail
2	P2751	Monorail Trolley
1	TC-522	Console Transport Case, MC-522/572
1	TC-0523	Pump Unit Transport Case
1	M5CO-SET	Calibration Critical Orifice Set

It is also recommended to have additional Probe Assemblies to best suit your testing needs. Apex Instruments, Inc. recommends a 4 foot and 8 foot Probe Assembly in addition to the standard 6 foot which is included in the above listed system.

Recommended Spare Parts for Isokinetic Sampling

Apex Instruments, Inc. recommends stocking the following spare parts:

Qty	Part #	Description
Console Meter Parts (MC-572)		
1	TC-765KF	Thermocouple Display, panel mount, LED, 120V/240V
1	M313102A	Thermocouple Switch, 7-Channel
1	M-31302K	Knob for 7-Channel Selector Switch
1	M-1400	Temperature Controller, analog, Love Model 140EF
2	SSR-330-25	Relay, SSRT, 25A, 120/240V
1	M-CB10A	Electrical Circuit Breaker, 10A, 120V, panel-mount
2	M-CB3A	Electrical Circuit Breaker, 3A, 120V, panel-mount
1	M-49BK	Electrical Receptacle, snap-in, screw-term, 120V
1	AM-MCP	Amphenol Connector, MC Panel, pre-wired sub
1	M-SV3131	Solenoid Valve, 3-way, brass, 120V
1	DGM-SK25	Dry Gas Meter, SK-25, Metric
1	QC-BHF4-B	Quick Connect, bulkhead, ¼”- ¼” tube, female, brass
1	QC-F8-B	Quick Connect, ½”- ½ ” tube, female, brass
1	QC-M6-B	Quick Connect, 3/8”- 3/8 ” tube, male, brass
1	QC-BHF6-B	Quick Connect, bulkhead, 3/8”- 3/8 ” tube, female, brass
1	M-42210	Dual Column Manometer, inclined vertical
1	QC-MAN-F3	Quick Connect, Manometer, female, 1/8” MNPT, stainless steel
2	QC-MAN-M2	Quick Connect, Manometer, male, 1/4” HB, P/C, PVC
2	M-422DS	Manometer Displacer, with knob
1	HC83314SS	Cabinet Spring Catch for Meter Console
1	HS83314SS	Keeper Latch, short shank for Meter Console
External Pump Parts (E-0523)		
1	GP-BL50-2	Mini Lubricator
4	AK731	Gast Vanes, Model E-0523 (4 Required)
1	QC-M6-B	Quick Connect, 3/8” – 3/8” tube, male, brass
1	QC-F6-B	Quick Connect, 3/8” – 3/8” tube, female, brass
Sample Case Parts (SB-1)		
1	AM-SBP	Amphenol Connector, SB panel, wired
1	TC-PJK	Thermocouple Jack, Type K, panel
1	AM-SB500W	Hot Box Heater, 500W, 240V
1	PC-1	Hinged Probe Clamp, stainless steel, (2.54 cm OD probes)

Recommended Spare Parts for Isokinetic Sampling

(continued)

Qty	Part #	Description
Umbilical Cable Parts (UC-60)		
1	QC-F4-B	Quick Connect, ¼" – ¼" tube, female, brass
1	QC-F8-B	Quick Connect, ½ " – ½ " tube, female, brass
1	QC-M4-B	Quick Connect, ¼" – ¼" tube, male, brass
1	QC-M8-B	Quick Connect, ½ " – ½ " tube, male, brass
4	TC-LPS-K	Thermocouple Plug, Type K, cord
4	TC-LJ-K	Thermocouple Connector, Type K, female
1	AM3101A	Amphenol Body, 4-pin cable
1	AM3106B	Amphenol Body, 4-socket, cable
2	AM3057	Amphenol Body, strain relief, cable
10	EXP-20	Expando, 1-1/4 inch 500 black
25	PT24004BK	PE Tubing, ¼ inch OD, weathered, black, 1000' roll
25	PT24004NA	PE Tubing, ¼ inch OD, weathered, Natural, 1000' roll
25	PT24004YW	PE Tubing, ¼ inch OD, weathered, yellow, 1000' roll
General Repair and Supply Parts		
50	WK-PP-24S	Wire, Thermocouple extension, yellow, feet
25	WK-TT-24	Wire, Thermocouple, Type K, TFE insulation, feet
10	4F-B	Ferrule, ¼ inch tube, brass
10	6F-B	Ferrule, 3/8 inch tube, brass
10	8F-B	Ferrule, ½ inch tube, brass
10	10F-B	Ferrule, 5/8 inch tube, brass
1	O-113-DZ	Silicone O-ring, 5/8 inch, 12 per pack
3	NTG-10F	Single Ferrule, 5/8 inch
1	3M-69	Glass Tape, Scotch 69, ¾". 66 ft. roll

Equipment Checklist

CLIENT/SOURCE _____ PROJECT # _____

SAMPLING EQUIPMENT

- ☐ METER BOX: QTY___ S/N _____
- ☐ PROBE: QTY___ FT _____
- ☐ PROBE BRUSH: FT _____
- ☐ NOZZLE BOX: GLASS/SS ___
- ☐ SAMPLE BOX: QTY _____
- ☐ IMPINGER BOX: QTY _____
- ☐ UMBILICAL QTY ___ FT ___
- ☐ REAGENT BOX _____
- ☐ FILTERS _____
- ☐ EXTENSION CORD: QTY___ FT ___
- ☐ ICE CHEST _____
- ☐ ROPE _____
- ☐ PULLEY & STAND _____
- ☐ C CLAMPS _____
- ☐ TRAY w/___ ' LEGS _____
- ☐ RAILS _____
- ☐ ROLLERS _____
- ☐ DUCT TAPE _____
- ☐ HEAT TAPE _____
- ☐ TARP _____
- ☐ _____

ORSAT EQUIPMENT

- ☐ ORSAT ANALYZER _____
- ☐ ORSAT PUMP - PERISTALTIC
- ☐ TUBING _____
- ☐ FYRITE
- ☐ SQUEEZE BULB _____
- ☐ SAMPLE BAGS/BUCKETS QTY _____
- ☐ ORSAT REAGENTS
- ☐ SPARE GLASSWARE/BAGS

SAFETY EQUIPMENT

- ☐ HARD HAT
- ☐ GLOVES
- ☐ RESPIRATOR
- ☐ EAR PLUGS
- ☐ SAFETY GLASSES
- ☐ RAIN GEAR
- ☐ SAFETY BELT

SAMPLE RECOVERY SUPPLIES & REAGENTS

- ☐ BALANCE _____
- ☐ FILTERS _____
- ☐ GRAD. CYL. (250 ML)
- ☐ TWEEZERS _____
- ☐ ALUM. FOIL _____
- ☐ SQUEEZE BOTTLES
- ☐ PETRI DISHES _____
- ☐ PARAFILM _____
- ☐ RUBBER GLOVES ___
- ☐ _____
- ☐ _____

- ☐ BRUSHES _____
- ☐ FUNNELS _____
- ☐ TFE TAPE _____
- ☐ _____

REAGENTS

- ☐ H20: TAP___ DD___
- ☐ ACETONE _____
- ☐ OTHER _____
- ☐ SILICA GEL _____
- ☐ ORSAT CHEM. _____
- ☐ _____

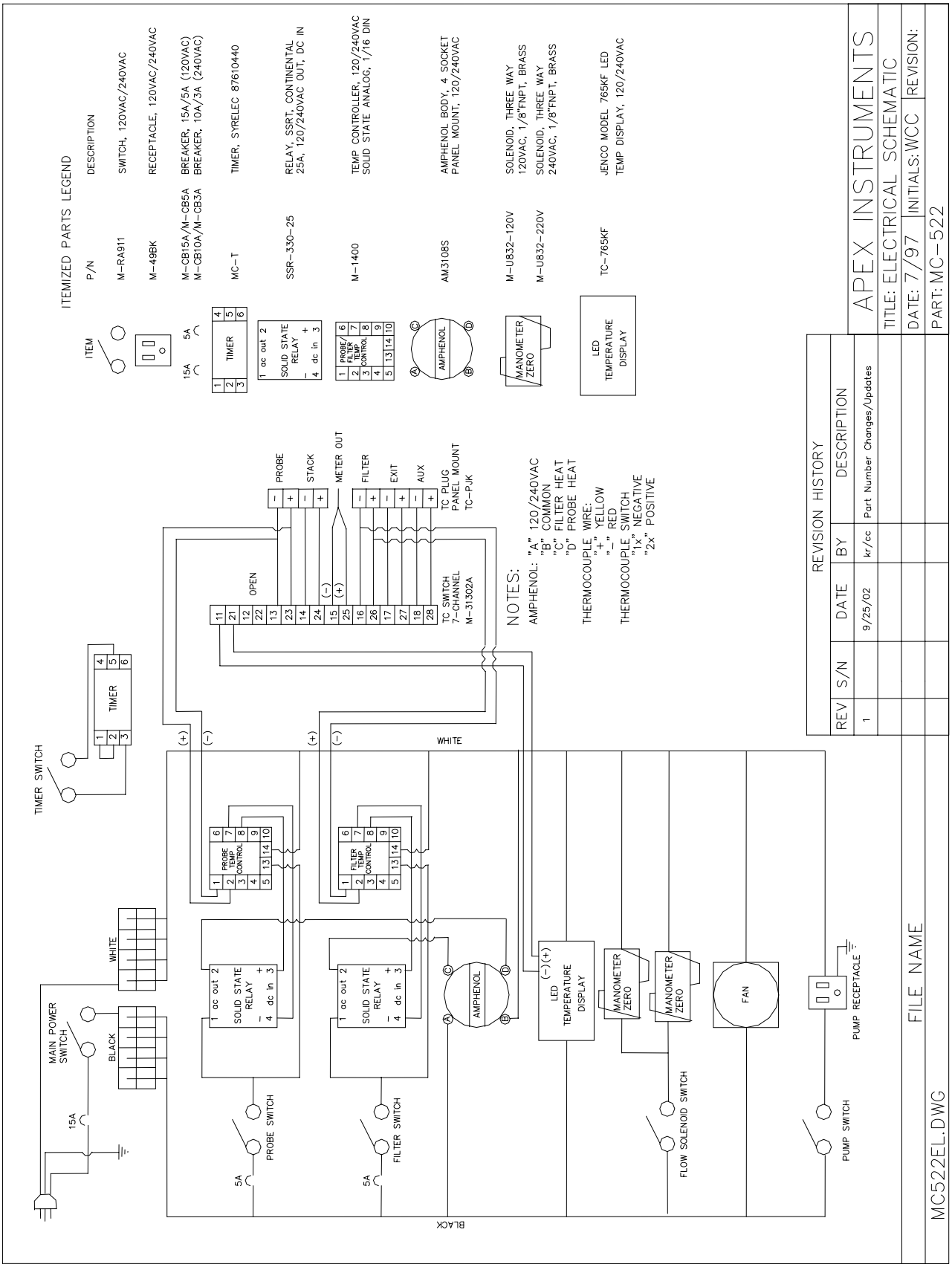
METER OPERATORS CASE (MOC BOX)

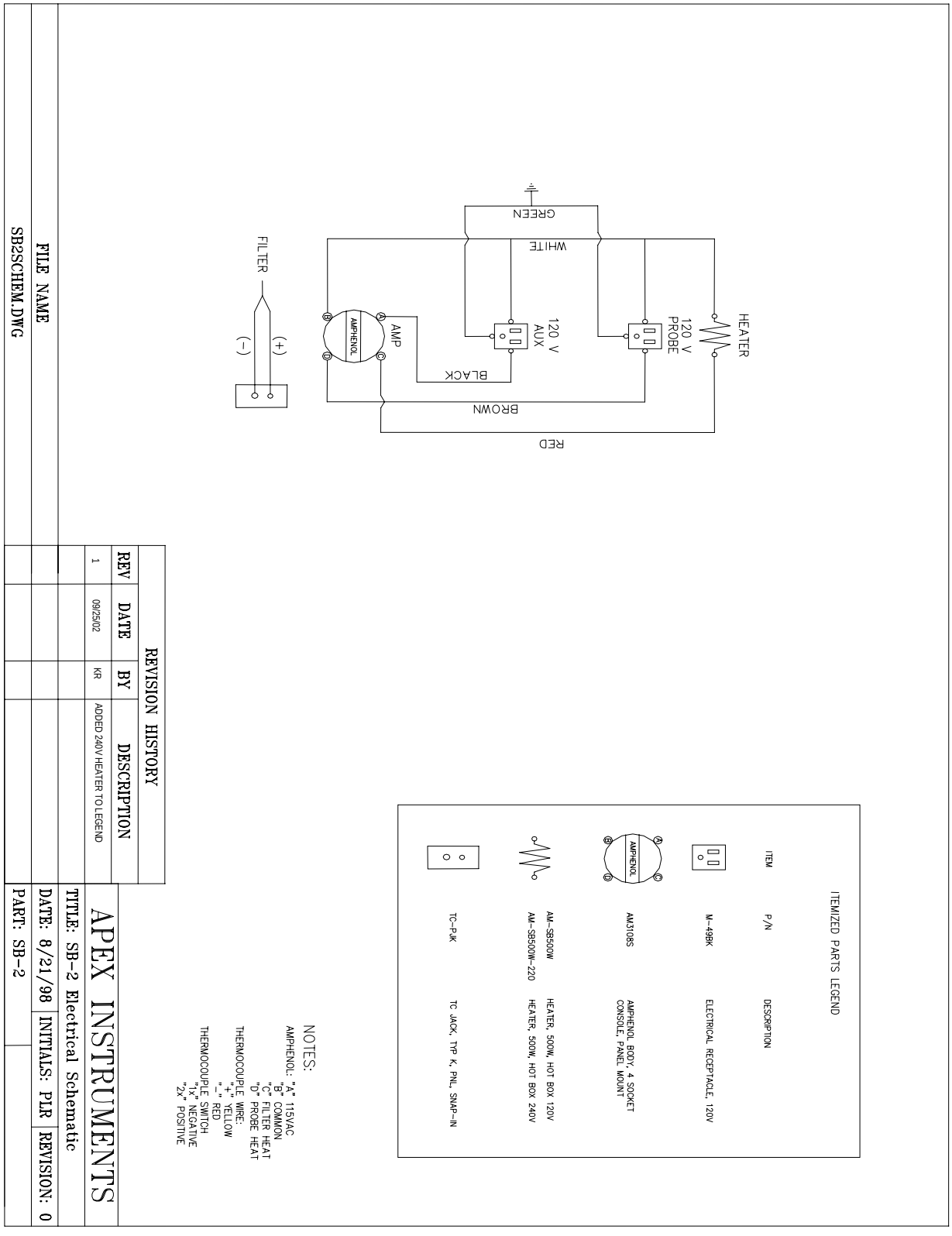
- ☐ NOMOGRAPH
- ☐ BAROMETER
- ☐ VAC. GAUGE
- ☐ SERUM CAPS
- ☐ ELEC. TAPE
- ☐ TOOLS
- ☐ WRENCHES
- ☐ SCREWDRIVER
- ☐ TAPE MEAS.
- ☐ _____
- ☐ MULTIMETER
- ☐ PENS
- ☐ CLIP BOARD
- ☐ _____
- ☐ _____

- ☐ COMPUTER
- ☐ PROGRAMS
- ☐ DATA SHEETS
- ☐ PROJECT FILE
- ☐ MAP/DIRECTIONS
- ☐ CALCULATOR
- ☐ STOP WATCH
- ☐ CFR/METHODS
- ☐ PRELIM. DATA
- ☐ _____

Appendix B

Electrical and Plumbing Schematics


ITEMIZED PARTS LEGEND
ITEM P/N DESCRIPTION
M-RA911 SWITCH, 120VAC/240VAC
M-49BK RECEPTACLE, 120VAC/240VAC
M-CB15A/M-CB5A BREAKER, 15A/5A (120VAC)
M-CB10A/M-CB3A BREAKER, 10A/3A (240VAC)
MC-T TIMER, SYRELEC 87610440
SSR-330-25 RELAY, SSRT, CONTINENTAL 25A, 120/240VAC OUT, DC IN
M-1400 TEMP. CONTROLLER, 120/240VAC SOLID STATE ANALOG, 1/16 DIN
AM3108S AMPHENOL BODY, 4 SOCKET PANEL MOUNT, 120/240VAC
M-U832-120V SOLENOID, THREE WAY 120VAC, 1/8"FNPT, BRASS
M-U832-220V SOLENOID, THREE WAY 240VAC, 1/8"FNPT, BRASS
TC-765KF JENCO MODEL 765KF LED TEMP DISPLAY, 120/240VAC
NOTES:
AMPHENOL: "A" 120/240VAC
"B" COMMON
"C" FILTER HEAT
"D" PROBE HEAT
THERMOCOUPLE WIRE:
"+" YELLOW
"-" RED
THERMOCOUPLE SWITCH
"1x" NEGATIVE
"2x" POSITIVE
REVISION HISTORY
REV S/N DATE BY DESCRIPTION
1 9/25/02 kr/cc Part Number Changes/Updates
APEX INSTRUMENTS
TITLE: ELECTRICAL SCHEMATIC
DATE: 7/97 INITIALS:WCC REVISION:
PART: MC-522
FILE NAME
MC522EL.DWG
MAIN POWER SWITCH
TIMER SWITCH
PROBE SWITCH
FILTER SWITCH
FLOW SOLENOID SWITCH
PUMP SWITCH
PUMP RECEPTACLE
SOLID STATE RELAY
PROBE/FILTER TEMP CONTROL
AMPHENOL
LED TEMPERATURE DISPLAY
MANOMETER ZERO
FAN
TIMER
TC SWITCH 7-CHANNEL M-313302A
TC PLUG PANEL MOUNT TC-PJK
PROBE
STACK
METER OUT
FILTER
EXIT
AUX
OPEN
WHITE
BLACK



ITEMIZED PARTS LEGEND

ITEM	P/N	DESCRIPTION
	M-498K	ELECTRICAL RECEPTACLE, 120V
AMPHENOL	AM3108S	AMPHENOL BODY, 4 SOCKET CONSOLE, PANEL MOUNT
	AM-SB500W	HEATER, 500W, HOT BOX 120V
	AM-SB500W-220	HEATER, 500W, HOT BOX 240V
	TC-PJK	TC JACK, TYP K, PNL, SNAP-IN

NOTES:
AMPHENOL: "A" 115VAC
"B" COMMON
"C" FILTER HEAT
"D" PROBE HEAT
THERMOCOUPLE WIRE:
"+" YELLOW
"-" RED
THERMOCOUPLE SWITCH
"1x" NEGATIVE
"2x" POSITIVE

REVISION HISTORY

REV	DATE	BY	DESCRIPTION
1	09/25/02	KR	ADDED 240V HEATER TO LEGEND

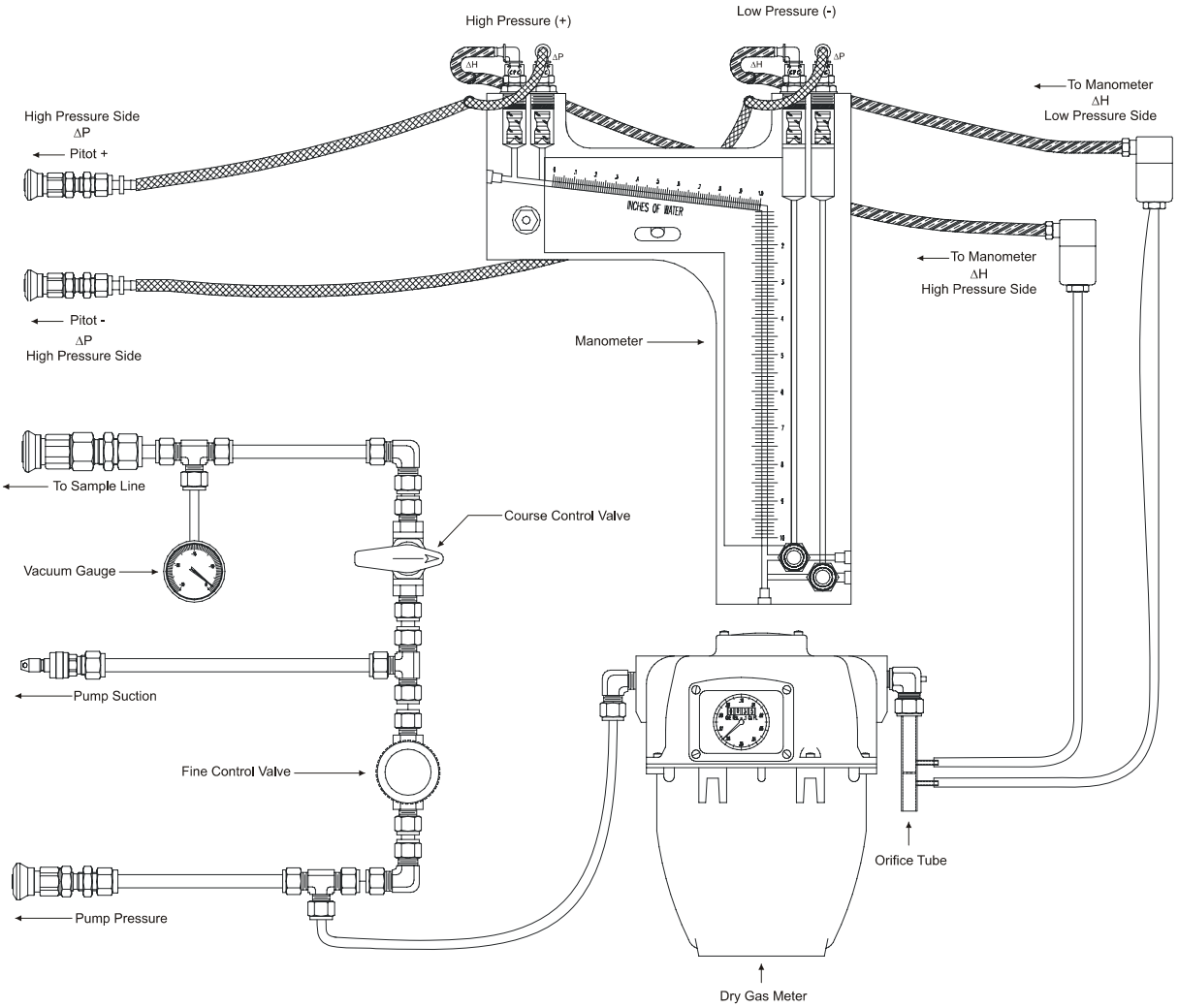
APEX INSTRUMENTS

TITLE: SB-2 Electrical Schematic

DATE: 8/21/98 | INITIALS: PLR | REVISION: 0

PART: SB-2

FILE NAME
SB2SCHEM.DWG



APEX INSTRUMENTS SOURCE TESTING EQUIPMENT	TITLE: MC522 Plumbing Schematic	REVISION HISTORY		
	PART #	DATE	BY	DESCRIPTION
	MATERIAL			
	DATE: 10/02/02			
FILE: mc522 plumbing schem.cdr	INITIALS: kr			

Appendix C

Calibration Data Sheets

APEX INSTRUMENTS METHOD 5 PRE-TEST CONSOLE CALIBRATION

USING WET-TEST METER _____

5-POINT METRIC UNITS

Meter Console Information	
Console Model Number	
Console Serial Number	
DGM Model Number	
DGM Serial Number	

Calibration Conditions			
Date	Time		
Barometric Pressure			mm Hg
Calibration Technician			
Calibration Meter Gamma			unitless

Factors/Conversions		
Std Temp	293	K
Std Press	760	mm Hg
K_1	0.386	

Calibration Data

Run Time	Metering Console					Calibration Meter			
Elapsed	DGM Orifice ΔH	Volume Initial	Volume Final	Outlet Temp Initial	Outlet Temp Final	Volume Initial	Volume Final	Outlet Temp Initial	Outlet Temp Final
(Θ)	(P_m)	(V_{mi})	(V_{mf})	(t_{mi})	(t_{mf})	(Vw_i)	(Vw_f)	(t_{wi})	(t_{wf})
min	mm H_2O	m^3	m^3	°C	°C	m^3	m^3	°C	°C

Results

Standardized Data				Dry Gas Meter				
				Calibration Factor		Flowrate	ΔH @	
Dry Gas Meter		Calibration Meter		Value	Variation	Std & Corr	.0212 m^3_{std}/min	Variation
($V_{m(std)}$)	($Q_{m(std)}$)	($Vw_{(std)}$)	($Qw_{(std)}$)	(Y)	(ΔY)	($Q_{m(std)(corr)}$)	(ΔH@)	(ΔΔH@)
m^3	m^3/min	m^3	m^3/min			m^3/min	mm H2O	
					Y Average			ΔH@ Average

Note: For Calibration Factor Y, the ratio of the reading of the calibration meter to the dry gas meter, acceptable tolerance of individual values from the average is +-0.02.

Note: For $\Delta H_@$, orifice pressure differential that equates to 0.75cfm (0.0212m^3/min) at standard temperature and pressure, acceptable tolerance of individual values from the average is +-0.2inches (5.1mm) H_2O.

I certify that the above Dry Gas Meter was calibrated in accordance with USEPA Methods, CFR 40 Part 60, using the Precision Wet Test Meter _____, which is traceable to the National Bureau of Standards (N.I.S.T.).

Signature _____ Date _____

APEX INSTRUMENTS METHOD 5 POST-TEST CONSOLE CALIBRATION

USING WET-TEST METER _____

3-POINT METRIC UNITS

Meter Console Information	
Console Model Number	
Console Serial Number	
DGM Model Number	
DGM Serial Number	

Calibration Conditions		
Date	Time	
Barometric Pressure		mm Hg
Calibration Technician		
Calibration Meter Gamma		unitless

Factors/Conversions		
Std Temp	293	K
Std Press	760	mm Hg
K_1	0.386	

Calibration Data

Run Time	Metering Console					Calibration Meter				
Elapsed	DGM Orifice ΔH	Volume Initial	Volume Final	Outlet Temp Initial	Outlet Temp Final	Volume Initial	Volume Final	Outlet Temp Initial	Outlet Temp Final
(Θ)	(P_{ds})	(V_{mi})	(V_{mf})	(t_{mi})	(t_{mf})	(Vw_i)	(Vw_f)	(t_{wi})	(t_{wf})
min	mm H_2O	m^3	m^3	°C	°C	m^3	m^3	°C	°C

Standardized Data

Dry Gas Meter	Calibration Meter	Calibration Factor	
(V_{mstd})	(Vw_{std})	(Qw_{std})	Value	Variation
m^3	m^3	m^3/min	(Y)	(ΔY)

Results

Dry Gas Meter			
Flowrate	ΔH@		
Std & Corr	.0212 m^3 sd/min	Variation	
($Q_{mstd(corr)}$)	(ΔH@)	(ΔΔH@)	
m^3/min	mm H2O		

Y Average	ΔH@ Average

Note: For Calibration Factor Y, the ratio of the reading of the calibration meter to the dry gas meter, acceptable tolerance of individual values from the average is +-0.02.

Note: For $\Delta H_@$, orifice pressure differential that equates to 0.75cfm (0.0212m^3/min) at standard temperature and pressure, acceptable tolerance of individual values from the average is +-0.2inches (5.1mm) H_2O.

I certify that the above Dry Gas Meter was calibrated in accordance with USEPA Methods, CFR 40 Part 60, using the Precision Wet Test Meter _____, which is traceable to the National Bureau of Standards (N.I.S.T.).

Signature _____ Date _____

APEX INSTRUMENTS METHOD 5 PRE-TEST CONSOLE CALIBRATION
USING CALIBRATED CRITICAL ORIFICES
5-POINT METRIC UNITS

Meter Console Information	
Console Model Number	
Console Serial Number	
DGM Model Number	
DGM Serial Number	

Calibration Conditions			
Date	Time		
Barometric Pressure			mm Hg
Theoretical Critical Vacuum[1]			mm Hg
Calibration Technician			

Factors/Conversions		
Std Temp	293	K
Std Press	760	mm Hg
K_1	0.386	

[1]For valid test results, the Actual Vacuum should be 25 to 50 mm Hg greater than the Theoretical Critical Vacuum shown above.

[2]The Critical Orifice Coefficient, K', must be entered in Metric units, $m^3*K^{1/2}/(mmHg*min)$.

Calibration Data										
Run Time	Metering Console					Critical Orifice				
Elapsed	DGM Orifice ΔH	Volume Initial	Volume Final	Outlet Temp Initial	Outlet Temp Final	Serial Number	Coefficient	Amb Temp Initial	Amb Temp Final	Actual Vacuum
(Θ)	(P_m)	(V_{mi})	(V_{mf})	(t_{mi})	(t_{mf})		K'	(t_{amb})	(t_{amb})	
min	mm H_2O	m^3	m^3	°C	°C		see above2	°C	°C	mm Hg

Results							
Standardized Data				Dry Gas Meter			
				Calibration Factor		Flowrate	ΔH @
Dry Gas Meter		Critical Orifice		Value	Variation	Std & Corr	.0212 m^3 std/min	Variation
($V_{m(std)}$)	($Q_{m(std)}$)	($Vcr_{(std)}$)	($Q_{cr(std)}$)	(Y)	(ΔY)	($Q_{m(std)corr}$)	(ΔH@)	(ΔΔH@)
m^3	m^3/min	m^3	m^3/min			m^3/min	mm H2O	
					Y Average			ΔH@ Average

Note: For Calibration Factor Y, the ratio of the reading of the calibration meter to the dry gas meter, acceptable tolerance of individual values from the average is +-0.02.

I certify that the above Dry Gas Meter was calibrated in accordance with USEPA Methods, CFR 40 Part 60, using the Precision Wet Test Meter _____, which is traceable to the National Bureau of Standards (N.I.S.T.).

Signature _____ Date _____

APEX INSTRUMENTS METHOD 5 POST-TEST CONSOLE CALIBRATION
USING CALIBRATED CRITICAL ORIFICES
3-POINT METRIC UNITS

Meter Console Information	
Console Model Number	
Console Serial Number	
DGM Model Number	
DGM Serial Number	

Calibration Conditions		
Date	Time	
Barometric Pressure		mm Hg
Theoretical Critical Vacuum[1]		mm Hg
Calibration Technician		

Factors/Conversions		
Std Temp	293	K
Std Press	760	mm Hg
K_t	0.386	

[1]For valid test results, the Actual Vacuum should be 25 to 50 mm Hg greater than the Theoretical Critical Vacuum shown above.

[2]The Critical Orifice Coefficient, K', must be entered in Metric units, $m^3K^{\circ 1/2}/(mmHg^*min)$.

Calibration Data																	
	Metering Console							Critical Orifice									
Run Time	DGM Orifice ΔH	Volume Initial	Volume Final	Outlet Temp Initial	Outlet Temp Final	Serial Number	Coefficient	Amb Temp Initial	Amb Temp Final	Actual Vacuum
Elapsed (Θ)	(P_a)	(V_{mi})	(V_{mf})	(t_{mi})	(t_{mf})			(t_{ami})	(t_{amf})	
min	mm H_2O	m^3	m^3	°C	°C		K'	°C	°C	mm Hg
							see above[2]			

Results								
	Standardized Data				Dry Gas Meter			
	Dry Gas Meter	Critical Orifice		Calibration Factor		Flowrate	ΔH @	
	(V_{mstd})	(Q_{std})	(Q_{std})	Value	Variation	Std & Corr	.0212 m^3 x ΔH@	Variation
	m^3	m^3/min	m^3/min	(Y)	(ΔY)	(Q_{corr})	(ΔH@)	(ΔΔH@)
						m^3/min	mm H2O	
				Y Average			ΔH@ Average	

Note: For Calibration Factor Y, the ratio of the reading of the calibration meter to the dry gas meter, acceptable tolerance of individual values from the average is +-0.02.

I certify that the above Dry Gas Meter was calibrated in accordance with USEPA Methods, CFR 40 Part 60, using the Precision Wet Test Meter_____, which is traceable to the National Bureau of Standards (N.I.S.T.).

Signature_____ Date_____

TEMPERATURE SENSOR CALIBRATION DATA SHEET

DATE _____ THERMOCOUPLE NO._____
PERSONNEL_____ REFERENCE:
AMBIENT TEMPERATURE_____°C ASTM MERCURY-IN-GLASS ID#_____
NIST REFERENCE TC ID#_____

Date	Reference Point Number	Source (Specifiy)	Reference Thermometer Temperature °C	Thermocouple Display Temperature °C	Absolute Temperature Difference %
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				
	1				
	2				
	3				

Checked by: _____ _____
Personnel (Signature/Date) Team Leader (Signature/Date)

PROBE NOZZLE DIAMETER CALIBRATION DATA SHEET

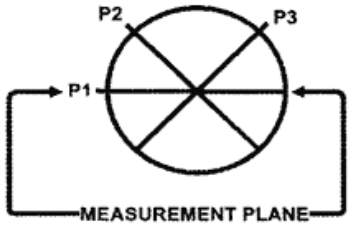
Date	Calibrated by	Nozzle ID #	Nozzle Diameter (mm)			Hi-Lo	
			D1	D2	D3	ΔD	D_{avg}

Where:

D1, D2, D3 = Three different nozzle diameters at 60 degrees to each other, each measured to the nearest 0.025mm

ΔD = Maximum distance between any two diameters, must be ≤ 0.100mm

D_{avg} = (D1 + D2 + D3) / 3



INSTRUCTIONS

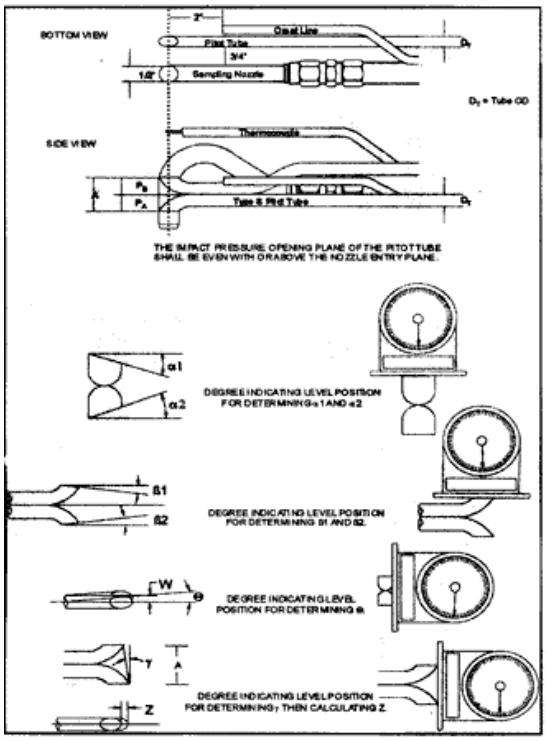
1. Inspect the nozzle for nicks, dents and corrosion. If these are found, they should be corrected before calibration.
2. Place a reference mark on the nozzle. Place the nozzle at the center of figure, aligned with point P1. Measure and and record D1.
3. Rotate the nozzle so that the reference mark is aligned with point P2. Measure and record D2.
4. Rotate the nozzle so that the reference mark is aligned with point P3. Measure and record D3.
5. Calculate ΔD and D_{avg}.

Checked by: _____ _____

Personnel (Signature/Date) Team Leader (Signature/Date)

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

Type S Pitot Tube Inspection Form



Parameter	Value	Allowable Range
Assembly Level?		Yes
Ports Damaged?		No
$\alpha 1$		$-10° < \alpha 1 < +10°$
$\alpha 2$		$-10° < \alpha 2 < +10°$
$\beta 1$		$-5° < b1 < +5°$
$\beta 2$		$-5° < \beta 2 < +5°$
γ		
θ		
$Z = A \tan \gamma$		$Z \leq .125"$
$W = A \tan \theta$		$W \leq .031"$
Dt		.188" to .375"
A		for 1/4" OD, .525 to .750" for 3/8" OD, .788 to 1.125"

Certification

I certify that pitot tube/probe number _____ meets or exceeds all specifications, criteria and/or applicable design features and is hereby assigned a pitot tube certification factor of 0.84. See 40 CFR Pt. 60, App. A, EPA Method 2.

Certified by:

_____ _____

Personnel (Signature/Date) **Team Leader (Signature/Date)**

PRESSURE SENSOR CALIBRATION DATA SHEET

(If other than inclined gauge-oil or mercury-in-glass)

Type of Pressure Sensor

- ☐ Differential Gauge
- ☐ Electronic Manometer
- ☐ U-Tube
- ☐ Other _____

____Low to high values span range of Δp's?		___Values span range of pressures?	
Level	**Gauge (A)**	**Reference (B)**	**A/B (0.95 to 1.05?)**
Pressure Side			
Low			
Mid			
High			
Vacuum Side			
Low			
Mid			
High			

Reference: Inclined oil-gauge or mercury-in-glass.

Checked by: _____ _____

Personnel (Signature/Date) Team Leader (Signature/Date)

Appendix D

Stack Testing Field Data Sheets

SOURCE SAMPLING TITLE PAGE

Source Information				
Plant Name				
Sampling Location				
Fuel or Source Type				
Fuel F-Factor				

Test Information			
Starting Test Date			
Project #			
Operator			
Standard Temperature			°C
Standard Pressure			mm Hg
Minimum required sample vol.			scm
Run Duration			Minutes
Base Run Number			
# of Ports Available			
# of Ports Used			
Port Inside Diameter			mm
Circular Stack?		☐	
Rectangular Stack?		☐	

Test Equipment Information			
Meter Box Number			
Meter Calibration Factor	(Y)		
Orifice Meter Coefficient	($\Delta H_@$)		in H_2O
Pitot Identification			
Pitot Tube Coefficient	(C_p)		
Orsat Identification			
Nozzle Number			
Nozzle Diameter	(D_n)		mm
Probe Number			
Probe Length			m
(SS, Glass ....) Liner Material			
Sample Case / Oven Number			
Impinger Case Number			
Acetone Lot Number			

Testing Company Information	
Company Name	
Address	
City, State Country Zip	
Project Manager	
Phone Number	
Fax Number	

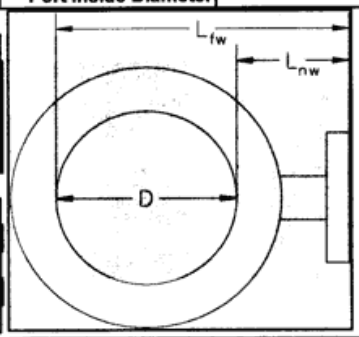
APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 1 - SAMPLE AND VELOCITY TRAVERSES FOR CIRCULAR SOURCES

Plant Name		Date	
Sampling Location		Project #	
Operator		# of Ports Available	
Stack Type		# of Ports Used	
Stack Size		Port Inside Diameter	

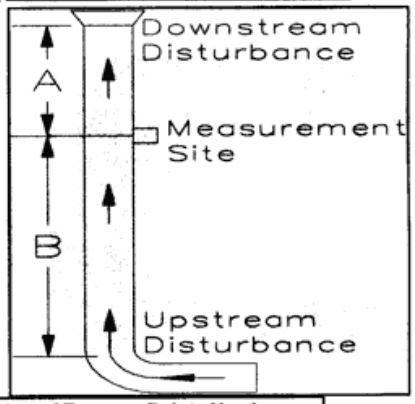
Circular Stack or Duct Diameter			
Distance to Far Wall of Stack	(L_{fw})		m
Distance to Near Wall of Stack	(L_{nw})		m
(=Lfw - Lnw) Diameter of Stack	(D)		m
(=3.14(D/2/Cunits)2) Area of Stack	(A_s)		m^2

Distance from Port to Disturbances			
Distance Upstream	(B)		m
(=B/D) Diameters Upstream	(B_D)		diameters
Distance Downstream	(A)		m
(=A/D) Diameters Downstream	(A_D)		diameters



Number of Traverse Points Required			
Diameters to Flow Disturbance		Minimum Number of[1] Traverse Points	
Up Stream	Down Stream	Particulate Points	Velocity Points
2.00-4.99	0.50-1.24	24	16
5.00-5.99	1.25-1.49	20	16
6.00-6.99	1.50-1.74	16	12
7.00-7.99	1.75-1.99	12	12
>= 8.00	>=2.00	8 or 12[2]	8 or 12[2]
Upstream Spec			
Downstream Spec			
Traverse Pts Required			

[1] Check Minimum Number of Points for the Upstream and Downstream conditions, then use the largest.
[2] 8 for Circular Stacks 12 to 24 inches
12 for Circular Stacks over 24 inches



Number of Traverse Points Used			
	Ports by		Across
	Pts Used		Required
☐	Particulate	☐	Velocity

Location of Traverse Points in Circular Stacks						
Traverse Point Number	(Fraction of Stack Diameter from Inside Wall to Traverse Point) Number of Traverse Points on a Diameter					
	2	4	6	8	10	12
1	.146	.067	.044	.032	.026	.021
2	.854	.250	.146	.105	.082	.067
3		.750	.296	.194	.146	.118
4		.933	.704	.323	.226	.177
5			.854	.677	.342	.250
6			.956	.806	.658	.356
7				.895	.774	.644
8				.968	.854	.750
9					.918	.823
10					.974	.882
11						.933
12						.979

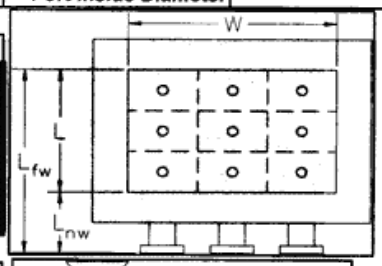
Traverse Point Number	Fraction of Stack Diameter	Distance from Inside Wall	Distance Including Nipple Length
		m	m
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

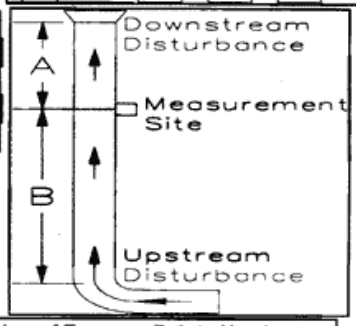
METHOD 1 - SAMPLE AND VELOCITY TRAVERSES FOR RECTANGULAR SOURCES

Plant Name		Date	
Sampling Location		Project #	
Operator		# of Ports Available	
Stack Type		# of Ports Used	
Stack Size		Port Inside Diameter	

Rectangular Stacks or Ducts			
Length to Far Wall of Stack	(L_{fw})		m
Length to Near Wall of Stack	(L_{nw})		m
(=Lfw - Lnw) Length of Stack	(L)		m
Width of Stack	(W)		m
(=2LW/(L+W)) Equivalent Stack Diam	(D_e)		m
(=LW/Cunits) Area of Stack	(A_s)		m^2



Distance from Port to Disturbances			
Distance Upstream	(B)		m
(=B/De) Diameters Upstream	(B_D)		diameters
Distance Downstream	(A)		m
(=A/De) Diameters Downstream	(A_D)		diameters



Number of Traverse Points Required			
Diameters to Flow Disturbance		Minimum Number of[1] Traverse Points	
Up Stream	Down Stream	Particulate Points	Velocity Points
2.00-4.99	0.50-1.24	25	16
5.00-5.99	1.25-1.49	20	16
6.00-6.99	1.50-1.74	16	12
7.00-7.99	1.75-1.99	12	12
>= 8.00	>=2.00	9 or 12[2]	9 or 12[2]
Upstream Spec			
Downstream Spec			
Traverse Pts Required			

[1] Check Minimum Number of Points for the Upstream and Downstream conditions, then use the largest.

[2] 9 for Rectangular Stacks 12 to 24 inches
12 for All Stacks over 24 inches

Number of Traverse Points Used			
	Ports by		Across
	Pts Used		Required
☐	Particulate	☐	Velocity

Traverse Point Number	Fraction of Stack Dimension	Distance from Inside Wall	Distance Including Nipple Length
		m	m
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Location of Traverse Points in Rectangular Stacks

Traverse Point Number	(Fraction of Stack Dimension from Inside Wall to Traverse Point) Number of Traverse Points Across the Stack										
	2	3	4	5	6	7	8	9	10	11	12
1	.250	.167	.125	.100	.083	.071	.063	.056	.050	.045	.042
2	.750	.500	.375	.300	.250	.214	.188	.167	.150	.136	.125
3		.833	.625	.500	.417	.357	.313	.278	.250	.227	.208
4			.875	.700	.583	.500	.438	.389	.350	.318	.292
5				.900	.750	.643	.563	.500	.450	.409	.375
6					.917	.786	.688	.611	.550	.500	.458
7						.929	.813	.722	.650	.591	.542
8							.938	.833	.750	.682	.625
9								.944	.850	.773	.708
10									.950	.864	.792
11										.955	.875
12											.958

APEX SOURCE TESTING EQUIPMENT INSTRUMENTS

METHOD 2 - DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE

Plant Name					Date		
Sampling Location					Project #		
Operator					# of Ports Used		
Stack Type					Pitot Identification		
Pitot Leak Check	☐	PreTest	☐	PostTest	Pitot Coefficient (C_p)		

Stack Dimensions			
Diameter or Length of Stack	(D)		m
Width of Stack	(W)		m
Area of Stack	(A_s)		m^2

Pressures			
Barometric Pressure	(P_b)		mm Hg
Static Pressure	(P_{static})		mm H_2O
Absolute Stack Pressure	(P_s)		mm Hg

Stack Gas Composition				
Composition Data:	Actual ☐		Estimated ☐	
Carbon Dioxide Concentration	(%CO_2)			%
Oxygen Concentration	(%O_2)			%
Carbon Monoxide Concentration	(%CO)			%
Nitrogen Concentration	(%N_2)			%
Stack Moisture Content	(B_{ws})			
Stack Dry Molecular Weight	(M_d)			g/g-mole
Stack Wet Molecular Weight	(M_s)			g/g-mole

Results			
Avg Stack Gas Velocity	(v_s)		m/sec
Avg Stack Dry Std Flow Rate	(Q_{sd})		dscm/hr
Avg Stack Dry Std Flow Rate	(Q_{sd})		dscm/min
Avg Stack Wet Flow Rate	(Q_{aw})		ascm/min

Stack Cross Section Schematic

Velocity Traverse Data

Run Number			
Run Time			
Traverse Point	Velocity Head (Δp)	Stack Temp (t_s)	Local Velocity $(v_s)_l$
	mm H_2O	°C	m/sec
$(\Delta p)^{1/2}{}_{avg}$ [1]			

[1] Average of the square roots of Δp

where $(\Delta p)^{1/2}{}_{avg} = {}^1/_n\Sigma(\Delta p^{1/2})$

Formulas Used

$A_s = DW/K_u$ for Rectangular Stacks

$A_s = (\pi(D/2)^2)/K_u$ for Circular Stacks

where $K_u = 1$ for metric units

where $K_u = 144$ (in^2/ft^2) for English units

$P_s = P_{bar} + P_{static}/13.6$

$\%N_2 = 100 - \%CO_2 - \%O_2 - \%CO$

$M_d = .44(\%CO_2) + .32(\%O_2) + .28(\%N_2 + \%CO)$

$M_s = M_d(1 - B_{ws}) + 18B_{ws}$

$(\Delta p)^{1/2}{}_{avg} = {}^1/_n\Sigma(\Delta p^{1/2})$

$T_{s(avg)} = {}^1/_n\Sigma t_s + T_u$

where $T_u = 273$ °K for metric units

where $T_u = 460$ °R for English units

$v_s = K_pC_p(\Delta p)^{1/2}{}_{avg}\,(T_{s(avg)}/(P_sM_s))^{1/2}$

where $K_p = 34.97$ for metric units

where $K_p = 85.49$ for English units

$Q_{sd} = 3600(1 - B_{ws})v_sA_s(T_{std}/T_{s(avg)})(P_s/P_{std})$

where $T_{std} = 293$ °K, $P_{std} = 760$ mm Hg, for metric units

where $T_{std} = 528$ °R, $P_{std} = 29.92$ in Hg, for English units

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 3 - GAS ANALYSIS FOR THE DETERMINATION OF DRY MOLECULAR WEIGHT

Plant Name					Date		
Sampling Location					Project #		
Operator					# of Ports Used		
Fuel Type			Minimum Fuel Factor			Maximum Fuel Factor	
Orsat Leak Check	☐	PreTest	☐	PostTest	Orsat Identification		

Gas Analysis Data

Run Number				Run Start Time			Run Stop Time		
Sample Analysis Time	Carbon Dioxide Volume (V_{CO2})	Oxygen Volume (V_{O2})	Carbon Monoxide Volume (V_{CO})	Carbon Dioxide Conc. ($\%CO_2$)	Oxygen Conc. ($\%O_2$)	Carbon Monoxide Conc. (%CO)	Nitrogen Conc. ($\%N_2$)	Dry Molecular Weight (M_d)	Molecular Weight Deviation (ΔM_d)
hh:mm	ml	ml	ml	percent	percent	percent	percent	g/g-mole	g/g-mole
Results			Averages						
Average Calculated Fuel Factor			$(F_o)_{avg}$			Molecular Wt Deviation < 0.3?			☐
Average Excess Air			$(\%EA)_{avg}$		percent	Fuel Factor in Handbook Range?			☐

Gas Analysis Data

Run Number				Run Start Time			Run Stop Time		
Sample Analysis Time	Carbon Dioxide Volume (V_{CO2})	Oxygen Volume (V_{O2})	Carbon Monoxide Volume (V_{CO})	Carbon Dioxide Conc. ($\%CO_2$)	Oxygen Conc. ($\%O_2$)	Carbon Monoxide Conc. (%CO)	Nitrogen Conc. ($\%N_2$)	Dry Molecular Weight (M_d)	Molecular Weight Deviation (ΔM_d)
hh:mm	ml	ml	ml	percent	percent	percent	percent	g/g-mole	g/g-mole
Results			Averages						
Average Calculated Fuel Factor			$(F_o)_{avg}$			Molecular Wt Deviation < 0.3?			☐
Average Excess Air			$(\%EA)_{avg}$		percent	Fuel Factor in Handbook Range?			☐

Gas Analysis Data

Run Number				Run Start Time			Run Stop Time		
Sample Analysis Time	Carbon Dioxide Volume (V_{CO2})	Oxygen Volume (V_{O2})	Carbon Monoxide Volume (V_{CO})	Carbon Dioxide Conc. ($\%CO_2$)	Oxygen Conc. ($\%O_2$)	Carbon Monoxide Conc. (%CO)	Nitrogen Conc. ($\%N_2$)	Dry Molecular Weight (M_d)	Molecular Weight Deviation (ΔM_d)
hh:mm	ml	ml	ml	percent	percent	percent	percent	g/g-mole	g/g-mole
Results			Averages						
Average Calculated Fuel Factor			$(F_o)_{avg}$			Molecular Wt Deviation < 0.3?			☐
Average Excess Air			$(\%EA)_{avg}$		percent	Fuel Factor in Handbook Range?			☐

Fuel Factor Fo

Fuel Type	Minimum	Maximum
Coal, Anthracite	1.016	1.130
Coal, Lignite	1.016	1.130
Coal, Bituminous	1.083	1.230
Oil, Distillate	1.260	1.413
Oil, Residual	1.210	1.370
Gas, Natural	1.600	1.836
Gas, Propane	1.434	1.586
Gas, Butane	1.405	1.553
Wood	1.000	1.120
Wood Bark	1.003	1.130

Formulas Used

$\%CO_2 = V_{CO2}$

$\%O_2 = V_{O2} - V_{CO2}$

$\%CO = V_{CO} - V_{O2}$

$\%N_2 = 100 - \%CO_2 - \%O_2 - \%CO$

$M_d = .44(\%CO_2) + .32(\%O_2) + .28(\%N_2 + \%CO)$

$\Delta M_d = M_d - M_{davg}$

$F_o = (20.9 - \%O_2 - .5\%CO)/(\%CO_2 + \%CO)$

$\%EA = (\%O_2 - .5\%CO)/(.264\%NO_2 - (\%O_2 - .5\%CO))$

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 4 - DETERMINATION OF MOISTURE CONTENT IN STACK GASES

Plant Name						Date		
Sampling Location						Project #		
Operator						# of Ports Used		
Stack Type						Meter Box Number		
Train Leak Check	☐	PreTest	☐	PostTest		Meter Cal Factor (Y)		

Moisture Content Data								
Run Number			Run Start Time			Run Stop Time		
Total Meter Volume	(V_m)		dcm	Barometric Press.		(P_b)		mm Hg
Avg Meter Temp	$(t_m)_{avg}$		°C	Stack Static Press.		(P_{static})		mm H_2O
Avg Stack Temp	$(t_s)_{avg}$		°C	Avg Orifice Press.		$(\Delta H)_{avg}$		mm H_2O
		Impinger 1	Impinger 2	Impinger 3	Impinger 4	Impinger 5	Impinger 6	Impinger 7
		ml	ml	ml	g	ml	ml	ml
Contents		DI	DI		Sil Gel			
Final Value	$(V_f),(W_f)$							
Initial Value	$(V_i),(W_i)$							
Net Value	$(V_n),(W_n)$							
Results								
Total Volume	(V_t)		ml	Water Vol Condensed		$(V_{wc(std)})$		scm
Total Weight	(W_t)		g	Water Vol Weighed		$(V_{wsg(std)})$		scm
Std Meter Volume	$(V_{m(std)})$		dscm	Sat. Moisture Content		$(B_{ws(svp)})$		%
Calc Moisture Content	$(B_{ws(calc)})$		%	Final Moisture Content		(B_{ws})		%

Moisture Content Data								
Run Number			Run Start Time			Run Stop Time		
Total Meter Volume	(V_m)		dcm	Barometric Press.		(P_b)		mm Hg
Avg Meter Temp	$(t_m)_{avg}$		°C	Stack Static Press.		(P_{static})		mm H_2O
Avg Stack Temp	$(t_s)_{avg}$		°C	Avg Orifice Press.		$(\Delta H)_{avg}$		mm H_2O
		Impinger 1	Impinger 2	Impinger 3	Impinger 4	Impinger 5	Impinger 6	Impinger 7
		ml	ml	ml	g	ml	ml	ml
Contents		DI	DI		Sil Gel			
Final Value	$(V_f),(W_f)$							
Initial Value	$(V_i),(W_i)$							
Net Value	$(V_n),(W_n)$							
Results								
Total Volume	(V_t)		ml	Water Vol Condensed		$(V_{wc(std)})$		scm
Total Weight	(W_t)		g	Water Vol Weighed		$(V_{wsg(std)})$		scm
Std Meter Volume	$(V_{m(std)})$		dscm	Sat. Moisture Content		$(B_{ws(svp)})$		%
Calc Moisture Content	(B_{ws})		%	Final Moisture Content		(B_{ws})		%

Moisture Content Data								
Run Number			Run Start Time			Run Stop Time		
Total Meter Volume	(V_m)		dcm	Barometric Press.		(P_b)		mm Hg
Avg Meter Temp	$(t_m)_{avg}$		°C	Stack Static Press.		(P_{static})		mm H_2O
Avg Stack Temp	$(t_s)_{avg}$		°C	Avg Orifice Press.		$(\Delta H)_{avg}$		mm H_2O
		Impinger 1	Impinger 2	Impinger 3	Impinger 4	Impinger 5	Impinger 6	Impinger 7
		ml	ml	ml	g	ml	ml	ml
Contents		DI	DI		Sil Gel			
Final Value	$(V_f),(W_f)$							
Initial Value	$(V_i),(W_i)$							
Net Value	$(V_n),(W_n)$							
Results								
Total Volume	(V_t)		ml	Water Vol Condensed		$(V_{wc(std)})$		scm
Total Weight	(W_t)		g	Water Vol Weighed		$(V_{wsg(std)})$		scm
Std Meter Volume	$(V_{m(std)})$		dscm	Sat. Moisture Content		$(B_{ws(svp)})$		%
Calc Moisture Content	(B_{ws})		%	Final Moisture Content		(B_{ws})		%

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

ISOKINETIC SAMPLING DATA

Plant Name		Date	
Sampling Location		Project #	
Operator		Run #	
# of Points Across		# of Ports Used	

Ideal Nozzle Diameter and IsoKinetic Factor Setup			
Pitot Tube Coefficient	(C_p)		
Avg Stack Temp	(t_s)		°C
Avg Gas Meter Temp	(t_m)		°C
DH @ 0.75 SCFM	($\Delta H@$)		mm H_2O
Avg Pitot Tube Diff. Pressure	(Δp_{avg})		mm H_2O
Stack Moisture Content	(B_{ws})		%
Stack Dry Molecular Weight	(M_{ds})		g/g-mole
Estimated Orifice Flow Rate	(Q_m)		acmm
DP to DH Isokinetic Factor	(K)		

Sampling Equipment			
Meter #			
Meterbox Cal. Factor	(Y)		
Nozzle #			
Actual Nozzle Diameter	(D_{na})		mm
Req. Nozzle Diameter	(D_{ni})		mm
Probe # / Length			m
Liner Material			
Sample Case / Oven #			
Impinger Case #			

Pressures			
Barometric Pressure	(P_b)		mm Hg
Stack Static Pressure	(P_{static})		mm H_2O
Absolute Stack Pressure	(P_s)		mm Hg
Absolute Meter Pressure	(P_m)		mm Hg

ΔV_m	Leak Checks				
Pre		m^3/min	@		mm Hg
Mid		m^3/min	@		mm Hg
Post		m^3/min	@		mm Hg
ΔV_m <		m^3/min	☐	Leak Check OK?	
Pitot OK?	☐		Orsat OK?	☐	

Traverse Point #	Sampling Time (Θ)	Clock Time	Dry Gas Meter Reading (V_m)	Velocity Head (Δp)	Desired Orifice ΔH (ΔH)	Actual Orifice ΔH (ΔH)	Stack Temp (t_s)	Probe Temp (t_{mi})	Meter Outlet Temp (t_{mo})	Filter Temp	Impinger Exit Temp	Pump Vacuum
	min	hh:mm:ss	m^3	mm H_2O	mm H_2O	mm H_2O	°C	°C	°C	°C	°C	mm Hg
Last Pt									Maximum Vacuum			
Average Values												

APEX SOURCE TESTING EQUIPMENT INSTRUMENTS

METHOD 5 - SAMPLE RECOVERY AND INTEGRITY DATA SHEET

Plant Name		Date	
Sampling Location		Project #	
Operator		Acetone Lot Number	

Run History Data				
Run Number				
Run Start Time				(hh:mm)
Run Stop Time				(hh:mm)
Train Prepared By				
Train Recovered By				
Recovery Date				(mm/dd/yy)
Relinquished By				
Received By				
Relinquished Date				(mm/dd/yy)
Relinquished Time				(hh:mm)

Equipment Identification Numbers			
Filter			
Acetone Wash			
Silica Gel			
Impinger Case			
Sample Box			
Oven			

Moisture Content Data					
Impingers 1, 2, and 3 - Water Volume					
Final Volume	(V_f)				ml
Initial Volume	(V_i)				ml
Net Volume	(V_n)				ml
Comments					
Impinger 4 - Silica Gel Weight					
Final Weight	(W_f)				g
Initial Weight	(W_i)				g
Net Weight	(W_n)				g
Comments					
Total Water Collected					
Total Volume	(V_{lc})				g

Formulas Used
$V_n = V_f - V_i$ $W_n = W_f - W_i$ $V_{lc} = V_n + W_n/\rho_w$ where $\rho_w = .9982$ g/ml

APEX SOURCE TESTING EQUIPMENT INSTRUMENTS

METHOD 5 - SAMPLE ANALYTICAL DATA SHEET

Plant Name		Date	
Sampling Location		Project #	
Operator		Acetone Lot Number	

Analytical Data

Placed in Desiccator	Number	Date	Time	Run Number	
				Run Start Time	
Filter				Leakage Evident?	☐
Acetone Wash Beaker				Estimated Volume	

		Filter	Acetone	Date	Time	Humidity	Temp	Cal Audit
		g	g	mm/dd/yy	hh:mm	%RH	°C	g
Measurement 1	(m_{1f}),(m_{1a})							
Measurement 2	(m_{2f}),(m_{2a})							
Measurement 3	(m_{3f}),(m_{3a})							
Measurement 4	(m_{4f}),(m_{4a})							

Results					Acetone Wash			
Final Weight	(m_{ff}),(m_{fa}')			g	Bottle Wt with Wash	(m_{bw})		g
Tare Weight	(m_{tf}),(m_{ta}')			g	Additional Rinse Wt	(m_{ar})		g
Weight Gain	(m_f),(m_a')			mg	Bottle Tare Weight	(m_{tb})		g
Blank Adjustment	(W_a)			mg	Net Wash Weight	(m_{nw})		g
Total Particulates	(m_n)			mg	Blank Concentration	(C_a)		mg/g

Analytical Data

Placed in Desiccator	Number	Date	Time	Run Number	
				Run Start Time	
Filter				Leakage Evident?	☐
Acetone Wash Beaker				Estimated Volume	

		Filter	Acetone	Date	Time	Humidity	Temp	Cal Audit
		g	g	mm/dd/yy	hh:mm	%RH	°C	g
Measurement 1	(m_{1f}),(m_{1a})							
Measurement 2	(m_{2f}),(m_{2a})							
Measurement 3	(m_{3f}),(m_{3a})							
Measurement 4	(m_{4f}),(m_{4a})							

Results					Acetone Wash			
Final Weight	(m_{ff}),(m_{fa}')			g	Bottle Wt with Wash	(m_{bw})		g
Tare Weight	(m_{tf}),(m_{ta}')			g	Additional Rinse Wt	(m_{ar})		g
Weight Gain	(m_f),(m_a')			mg	Bottle Tare Weight	(m_{tb})		g
Blank Adjustment	(W_a)			mg	Net Wash Weight	(m_{nw})		g
Total Particulates	(m_n)			mg	Blank Concentration	(C_a)		mg/g

Analytical Data

Placed in Desiccator	Number	Date	Time	Run Number	
				Run Start Time	
Filter				Leakage Evident?	☐
Acetone Wash Beaker				Estimated Volume	

		Filter	Acetone	Date	Time	Humidity	Temp	Cal Audit
		g	g	mm/dd/yy	hh:mm	%RH	°C	g
Measurement 1	(m_{1f}),(m_{1a})							
Measurement 2	(m_{2f}),(m_{2a})							
Measurement 3	(m_{3f}),(m_{3a})							
Measurement 4	(m_{4f}),(m_{4a})							

Results					Acetone Wash			
Final Weight	(m_{ff}),(m_{fa}')			g	Bottle Wt with Wash	(m_{bw})		g
Tare Weight	(m_{tf}),(m_{ta}')			g	Additional Rinse Wt	(m_{ar})		g
Weight Gain	(m_f),(m_a')			mg	Bottle Tare Weight	(m_{tb})		g
Blank Adjustment	(W_a)			mg	Net Wash Weight	(m_{nw})		g
Total Particulates	(m_n)			mg	Blank Concentration	(C_a)		mg/g

Formulas Used

m_{ff} = average of last two filter measurements

m_{fa}' = average of last two acetone measurements

$m_f = m_{ff} - m_{tf}$

$m_a' = m_{fa}' - m_{ta}'$

$W_a = C_a m_{nw}$

$m_{nw} = m_{bw} + m_{ar} - m_{tb}$

$m_n = m_f + m_a' - W_a$

APEX INSTRUMENTS SOURCE TESTING EQUIPMENT

METHOD 5 - DETERMINATION OF PARTICULATE EMISSIONS - RESULTS

Plant Name		Date	
Sampling Location		Project #	
Operator		Stack Type	

Historical Data						
Run Number					Average	
Run Start Time						hh:mm
Run Stop Time						hh:mm
Meter Calibration Factor	(Y)					
Pitot Tube Coefficient	(C_p)					
Actual Nozzle Diameter	(D_{na})					mm
Stack Test Data						
Initial Meter Volume	($V_m)_i$					m^3
Final Meter Volume	($V_m)_f$					m^3
Total Meter Volume	(V_m)					m^3
Total Sampling Time	(Θ)					min
Average Meter Temperature	($t_m)_{avg}$					°C
Average Stack Temperature	($t_s)_{avg}$					°C
Barometric Pressure	(P_b)					mm Hg
Stack Static Pressure	(P_{static})					mm H_2O
Absolute Stack Pressure	(P_s)					mm Hg
Average Orifice Pressure Drop	($\Delta H)_{avg}$					mm H_2O
Absolute Meter Pressure	(P_m)					mm Hg
Avg Square Root Pitot Pressure	($\Delta p^{1/2})_{avg}$					$(mm\ H_2O)^{1/2}$
Moisture Content Data						
Impingers 1-3 Water Volume Gain	(V_n)					ml
Impinger 4 Silica Gel Weight Gain	(W_n)					g
Total Water Volume Collected	(V_{lc})					ml
Standard Water Vapor Volume	($V_w)_{std}$					scm
Standard Meter Volume	($V_m)_{std}$					dscm
Calculated Stack Moisture	($B_{ws(calc)}$)					%
Saturated Stack Moisture	($B_{ws(svp)}$)					%
Reported Stack Moisture Content	(B_{ws})					%
Gas Analysis Data						
Carbon Dioxide Percentage	(%CO_2)					%
Oxygen Percentage	(%O_2)					%
Carbon Monoxide Percentage	(%CO)					%
Nitrogen Percentage	(%N_2)					%
Dry Gas Molecular Weight	(M_d)					g/g-mole
Wet Stack Gas Molecular Weight	(M_s)					g/g-mole
Calculated Fuel Factor	(F_o)					
Fuel F-Factor	(F_d)					dscf/mmBtu
Percent Excess Air	(%EA)					%
Volumetric Flow Rate Data						
Average Stack Gas Velocity	(v_s)					m/sec
Stack Cross-Sectional Area	(A_s)					m^2
Actual Stack Flow Rate	(Q_{aw})					acmm
Wet Standard Stack Flow Rate	(Q_{sw})					wkscfh
Dry Standard Stack Flow Rate	(Q_{sd})					dscmm
Percent of Isokinetic Rate	(I)					%
Emission Rate Data						
Mass of Particulate on Filter	(m_f)					mg
Mass of Particulate in Acetone	(m_a')					mg
Mass due to Acetone Blank	(W_a)					mg
Total Mass of Particulates	(m_n)					mg
Stack Particulate Concentration	(c_s)					g/dscm
	(c_s)					gr/dscm
Particulate Emission Rate	(E)					kg/hr
	(E)					lbs/hr
	(E)					lbs/mmBtu
(Pt 75 App F Sect. 5.2.1) Heat Input	(HI)					mmBtu/Hr

Appendix E

Calculation Worksheets

FEDERAL REFERENCE METHOD 1
Sample and Velocity Traverses for Stationary Sources

Plant _____ **Date** _____

Location _____ **Test No.** _____

INPUT PARAMETERS

Sketch of Stack Geometry

Circular Stack:

Interior duct cross-section diameter **= _____ m or ft.**

Sampling port diameter **= _____ cm or in.**

Sampling port nipple length **= _____ cm or in.**

Stack cross-sectional area **= _____ m^2 or ft^2**

Rectangular Stack:

Length of stack location (L) **= _____ m or ft.**

Width of Stack location (W) **= _____ m or ft.**

Equivalent diameter $D_e = \frac{2LW}{(L+W)}$ **= _____ m or ft.**

Sampling Site:

Diameter downstream of disturbance **= _____ m or ft.**

Diameter upstream of disturbance **= _____**

Minimum number of sampling points **= _____**

Total sampling time **= _____ min**

Individual point sampling times **= _____ min**

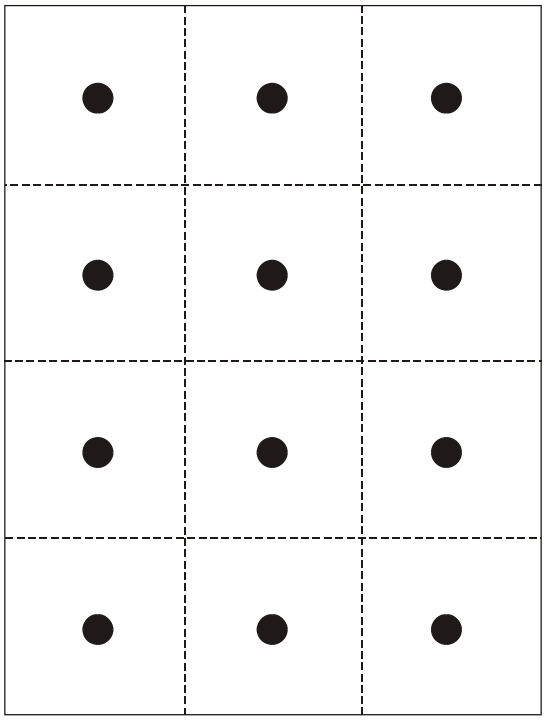
Sample and Velocity Traverses for Stationary Sources
(continued)

Location of Sampling Points:

CIRCULAR

Sample point number	Circular stack % diameter	Distance from sample port opening, in.
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		

RECTANGULAR



FEDERAL REFERENCE METHOD 2
Determination of Stack Gas Velocity and Volumetric Flow Rate
(Type S Pitot Tube)

Plant _____ **Date** _____

Location _____ **Test No.** _____

INPUT PARAMETERS

Area of stack (m2) or (ft^2) = πr^2 or π $(D/2)^2$ or L x W	=	A_s	= _____
Pitot tube coefficient	=	C_p	= _____
Stack gas temperature (K) = °C + 273° or (°R) = °F + 460°	=	T_s	= _____
Average of square root of velocity head (mm. H_2O)$^{1/2}$ or (in. H_2O)$^{1/2}$	=	$(\sqrt{\Delta p})_{avg}$	= _____
Barometric pressure (mm. Hg) or (in. Hg)	=	P_{bar}	= _____
Stack gas static pressure (mm. H_2O) or (in. H_2O)	=	P_g	= _____
Absolute stack gas pressure (mm. Hg) or (in. Hg)	=	P_s	= _____

Note: $P_s = P_{bar} + P_g$ (mm. H_2O)/13.6 or (in. H_2O)/13.6

Stack gas moisture (fraction)	=	B_{ws}	= _____
Stack gas dry molecular weight (g/g-mole) or (lb/lb-mole)	=	M_d	= _____
Stack gas wet molecular weight (g/g-mole) or (lb/lb-mole)	=	M_s	= _____

Note: $M_s = M_d (1 - B_{ws}) + 18.0\ B_{ws}$

CALCULATIONS

v_S = Stack gas velocity, m/s or ft/s

$$v_s = K_p \ x \ C_p \ x \ (\sqrt{\Delta p})_{avg} \ x \ \sqrt{\frac{T_{s(avg)}}{P_s \ M_s}}$$

$$v_s = K_p \ x \ (\quad) \ x \ (\quad) \ x \ \sqrt{\frac{(\quad)}{(\quad) x (\quad)}}$$ = _____ **m/s or ft/s**

K_p = 34.97 (Metric Units)
= 85.49 (English Units)

Q_a = Volumetric flow rate, acmm or acfm

$$Q_a = 60 \ x \ v_s \ x \ A_s$$

$$Q_a = 60 \ x \ (\quad) \ x \ (\quad)$$ = _____ **acmm or acfm**

Determination of Stack Gas Velocity and Volumetric Flow Rate
(continued)

Q_d = Dry volumetric flow meter, scmm or scfm

$$Q_d = 60\ x\ (1-B_{ws})\ x\ v_s\ x\ A_s$$

$$Q_d = 60\ x\ (1-(\quad))\ x\ (\quad)\ x\ (\quad) \quad = \underline{\qquad\qquad}\textbf{scmm or scfm}$$

Q_{sd} = Volumetric flow rate, dscmm or dscfm

$$Q_{sd} = 60\ x\ (1-B_{ws})\ x\ v_s\ x\ A_s\ x\ \frac{T_{std}}{T_s}\ x\ \frac{P_s}{P_{std}}$$

$$Q_{sd} = 60\ x\ (1-(\quad))\ x\ (\quad)\ x\ (\quad)\ x\ \frac{T_{std}}{(\quad)}\ x\ \frac{(\quad)}{P_{std}}$$

= _____**dscmm or dscfm**

FEDERAL REFERENCE METHOD 3
Gas Analysis for the Determination of Dry Molecular Weight

Plant _____ Date _____

Location _____ **Test No.** _____

INPUT PARAMETERS

Percent Oxygen (O_2) by volume, dry basis	=	**$\%O_2$**	= _____
Percent Carbon Dioxide (CO_2) by volume, dry basis	=	**$\%CO_2$**	= _____
Percent Carbon Monoxide (CO) by volume, dry basis	=	**%CO**	= _____
Percent N_2 = 100 – ($\%O_2$ + $\%CO_2$ + %CO)	=	**$\%N_2$**	= _____

CALCULATIONS

M_d = Dry molecular weight, g/g-mole or lb/lb-mole

$$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2 + \%CO)$$

$$M_d = 0.44(\quad) + 0.32(\quad) + 0.28(\quad + \quad) = \_\_\_\_\_ \textbf{g/g-mole or lb/lb-mole}$$

M_s = Wet molecular weight, g/g-mole or lb/lb-mole

$$M_s = M_d\,(1 - B_{ws}) + 18.0\,(B_{ws})$$

$$M_s = (\quad)(1-(\quad)) + 18.0(\quad) \quad = \_\_\_\_\_ \textbf{ g/g-mole or lb/lb-mole}$$

%EA = Excess Air, %

$$\%EA = \frac{(\%O_2) - (0.5\%CO)}{0.264(\%N_2) - (\%O_2 - 0.5\%CO)}\ x\ 100$$

$$\%EA = \frac{(\quad) - (0.5(\quad))}{0.264(\quad) - ((\quad) - 0.5(\quad))}\ x\ 100 \quad = \_\_\_\_\_ \textbf{\%}$$

FEDERAL REFERENCE METHOD 4
Determination of Moisture Content of Stack Gases

Plant _____ **Date** _____

Location _____ **Test No.** _____

INPUT PARAMETERS

Volume of gas sampled through dry gas meter	=	V_m	= _____
Dry gas meter (DGM) calibration factor	=	Y	= _____
Average DGM temperature (K) = °C + 273° or (°R) = °F + 460°	=	T_m	= _____
Average DGM orifice pressure differential (mm H_2O) or (in. H_2O)	=	ΔH	= _____
Volume of water collected, condensed, [V_f - V_i], ml	=	V_{lc}	= _____
Volume of water collected in silica gel (W_f – W_i), g	=	V_{wsg}	= _____
Barometric pressure (mm. Hg.) or (in. Hg)	=	P_{bar}	= _____

CALCULATIONS

$V_{m(std)}$ = Volume of gas sampled at standard conditions, dscm or dscf

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{P_{std}}\right) x \frac{P_{bar} + \left(\frac{\Delta H}{13.6}\right)}{T_m}$$

$$V_{m(std)} = (\quad)\ (\quad)\left(\frac{T_{std}}{P_{std}}\right)\frac{(\quad) + \left(\frac{(\quad)}{13.6}\right)}{(\quad)}$$ = _____**dscm or dscf**

$V_{wc(std)}$ = Volume of water vapor condensed at standard conditions, scm or scf

$$V_{wc(std)} = K_2\left(V_f - V_i\right)$$

$$V_{wc(std)} = K_2(\quad)$$ = _____**scm or scf**

K_2 = 0.001333 (Metric Units)
0.04706 (English Units)

Determination of Moisture Content of Stack Gases
(continued)

$V_{wsg(std)}$ = Volume of water vapor collected in silica gel

$$V_{wsg(std)} = K_3 \left(W_f - W_i\right)$$

$$V_{wsg(std)} = K_3 \left(\quad\right) \quad = \_\_\_\_\_ \textbf{scm or scf}$$

K_3 = 0.001333 (Metric Units)
0.04706 (English Units)

B_{ws} = Mole fraction of water vapor

$$B_{ws} = \frac{V_{wc(std)} + V_{wsg(std)}}{V_{wc(std)} + V_{wsg(std)} + V_{m(std)}}$$

$$B_{ws} = \frac{\left(\quad\right)+\left(\quad\right)}{\left(\quad\right)+\left(\quad\right)+\left(\quad\right)} \quad = \_\_\_\_\_$$

$\%H_2O$ = Percent moisture

$$\%H_2O = 100\ x\ B_{ws}$$

$$\%H_2O = 100\ x \left(\quad\right) \quad = \_\_\_\_\_ \textbf{\%}$$

FEDERAL REFERENCE METHOD 5
Nozzle Size Selection Worksheet

Note: *The most commonly used equation for estimating isokinetic sampling nozzle diameter is the following (assumes that moisture fraction at dry gas meter equals zero.):*

$$D_{n(est)} = \sqrt{\frac{K_1 Q_m P_m}{T_m C_p (1 - B_{ws})}} \sqrt{\frac{T_s M_s}{P_s \Delta p_{avg}}}$$

K1 = 0.6071 (Metric Units)
= 0.03575 (English Units)

Source Name _____ **Date** _____

Facility _____ **Calculated by** _____

INPUT DATA

Barometric Pressure (mm. Hg) or (in. Hg) **=** **P_{bar}** **=** _____

Stack Static Pressure (mm. H_2O) or (in. H_2O) **=** **P_g** **=** _____

Stack Gas Pressure (mm. Hg) or (in. Hg)

$$P_s = P_{bar} + \frac{P_g}{13.6}$$

$$P_s = (\quad) + \frac{(\quad)}{13.6}$$ **=** **P_s** **=** _____

Dry Gas Molecular Weight (g/g-mole) or (lb/lb-mole) **=** **M_d** **=** _____
assume 30.0 for combustion of coal, oil or gas
assign 29.0 if mostly air
assign 28.0 if mostly purge nitrogen
or use preliminary Orsat® or Fyrite® data

Stack Gas Moisture (fraction) **=** **B_{ws}** **=** _____
use preliminary moisture data
use wet bulb/dry bulb if < 212°F
BE CAREFUL: fraction B_{ws} = $\%H_2O/100$

Wet Gas Molecular Weight (g/g-mole) or (lb/lb-mole)

$$M_s = M_d (1 - B_{ws}) + 18.0 (B_{ws})$$

$$M_s = (\quad)(1 - (\quad)) + 18.0(\quad)$$ **=** **M_s** **=** _____

Stack Gas Temperature (K) or (°R) **=** **T_s** **=** _____

°C + 273° = K or °F + 460 = °R

Pitot Tube Coefficient **=** **C_p** **=** _____

Nozzle Size Selection Worksheet
(continued)

Average Velocity Head (mm. H_2O) or (in. H_2O) = Δp_{avg} = _____

v = calculation of inside square root term

$$v = \sqrt{\frac{T_s M_s}{P_s \Delta p_{avg}}}$$

$$v = \sqrt{\frac{(\quad) x (\quad)}{(\quad) x (\quad)}}$$ = **v** = _____

Sampling Flow Rate (cfm or lpm) = Q_m = _____
assume 0.75 cfm
assume 21.24 lpm

Dry Gas Meter Temperature (K or °R) = T_m = _____
use ambient temp + 25°F + 460 = °R

Dry Gas Meter Pressure (mm Hg or in. Hg) = P_m = _____
use P_{bar} + ($\Delta H_@$)/13.6

CALCULATION OF NOZZLE SIZE

Estimated Nozzle Diameter (mm or inches)

$$D_{n(est)} = \sqrt{\frac{K_1 Q_m P_m}{T_m C_p (1 - B_{ws})} \sqrt{\frac{T_s M_s}{P_s \Delta p_{avg}}}}$$

$$D_{n(est)} = \sqrt{\frac{K_1 \; x (\quad) x (\quad) x (\quad)}{(\quad) x (\quad) x (1 - (\quad))}}$$ = $D_{n(est)}$ = _____

K_1 = 0.6071 (Metric Units)
= 0.03575 (English Units)

Actual Nozzle Diameter Chosen (mm or inches) = D_n = _____

Nozzle Size Selection Worksheet
(continued)

K-FACTOR CALCULATION

ΔH **=** Isokinetic Rate Orifice Pressure Differential

$$\Delta H = Kx\Delta p$$

$$K = \frac{\Delta H}{\Delta p} = K_6 \; D_n^4 \; \Delta H_@ \; C_p^2 \left(1 - B_{ws}\right)^2 \frac{M_d \; T_m \; P_s}{M_s \; T_s \; P_m}$$

$$K = \frac{\Delta H}{\Delta p} = K_6 \; (\quad)^4 \; (\quad) \; (\quad)^2 \; (1 - (\quad))^2 \frac{(\quad)(\quad)(\quad)}{(\quad)(\quad)(\quad)}$$ **=** _____

K_6 = 8.038×10^{-5} (Metric Units)
= 846.72 (English Units)

CHECK CALCULATIONS FOR SUFFICIENT SAMPLE VOLUME AND ISOKINETIC RATE 90-110%

Stack Gas Velocity (m/s or ft/sec) **=** v_s **=** _____
from preliminary velocity run
convert to m/min or ft/min **v_s x 60 sec/min** **=** $v_{s(fpm) \text{ or } (mpm)}$ **=** _____

Estimated Sampling Time (minutes) **=** **θ** **=** _____

multiply number of traverse points by minutes/point **=** _____**total min.**

CALCULATION OF ACTUAL SAMPLING RATE

$Q_{m(std)}$ = Actual Sampling Rate (dscmm or dscfm)

$$Q_{m(std)} = \frac{100\left(1 - B_{ws}\right) P_s \; v_{s(\,fpm)or(mpm)} \; D_n^2}{1039\, T_s}$$

$$Q_{m(std)} = \frac{100(1 - (\quad))(\quad)(\quad)(\quad)^2}{1039(\quad)}$$ **=** _____

$V_{m(std)}$ = Total Gas Sample Volume to be Collected (dscm or dscf)

$$V_{m(std)} = Q_{m(std)} \; x \; \theta$$ **=** _____

Based on applicable regulations for this source:

Will there be sufficient sample volume (dscf)? ☐ **yes** ☐ **no**

Will there be sufficient sampling time (minutes)? ☐ **yes** ☐ **no**

Nozzle Size Selection Worksheet
(continued)

Check Intermediate Isokinetic Sampling Rate

$$\%I_i = \frac{100 T_s V_{m(std)} P_{std}}{60 T_{std} v_s \theta A_n P_s (1 - B_{ws})} = \frac{K_4 T_s V_{m(std)}}{P_s v_s A_n \theta (1 - B_{ws})}$$

$$\%I_i = \frac{K_4 (\quad)(\quad)(\quad)}{(\quad)(\quad)(\quad)(\quad)(1-(\quad))}$$ = _____

K_4 = 4.320 (Metric Units)
= 0.09450 (English Units)

Check Final Isokinetic Sampling Rate

A_n = Nozzle Area $\frac{\pi}{4} D_n^2$ = _____ in^2 or mm^2

$$\%I_f = \frac{100 T_{s(avg)} \left[K_3 V_{lc} + \left(\frac{V_{m(tot)}}{T_{m(avg)}} \right) \left(P_{bar} + \frac{\Delta H}{13.6} \right) \right]}{60 \theta v_{s(avg)} P_s A_n}$$

$$\%I_f = \frac{100(\quad) \left[K_3(\quad) + \left(\frac{(\quad)}{(\quad)} \right) \left((\quad) + \frac{(\quad)}{13.6} \right) \right]}{60(\quad)(\quad)(\quad)(\quad)}$$ = _____

K_3 = 0.003454 (Metric Units)
= 0.002669 (English Units)